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ASSESSMENT OF FLUIDIZED-BED COMBUSTION SOLID WASTES FOR LAND DISPOSAL

Volume 3. Appendices D and E

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16. ABSTRACT

The report, including 10 appendices, gives results of: (1) an analysis of representative samples of fluidized-bed combustion (FBC) wastes, (2) an assessment of the characteristics of leachates generated from the wastes under laboratory and field (landfill) conditions, (3) a characterization of the attenuation of the leachates by earth materials that are typical of disposal settings, (4) development of a way to predict the leachate generation behavior of FBC wastes under landfill conditions on the basis of laboratory test results by establishing a rigorous statistical relationship between the laboratory and field leaching results, and (5) assessment of the compatibility of commonly used landfill liner materials with FBC waste leachates. FBC is an emerging energy technology that holds promise for both high efficiency of energy conversion and minimization of adverse air quality impacts. A major advantage of FBC is that high-sulfur coal can be burned without the use of flue gas desulfurization equipment to meet air quality standards. The solid residues that are generated in an FBC unit are usually larger in volume and have different properties than the typical bottom ash from a conventional boiler.

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Pollution	Assessments	Pollution Control	13B	14B
Waste Disposal	Desulfurization	Stationary Sources		07A, 07D
Combustion	Earth Fills		21B	13C
Fluidized Bed	Linings			11G
Processing	Sorbents		13H	
Coal			21D	

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Abstract

The report, including 10 appendices, gives results of: (1) an analysis of representative samples of fluidized-bed combustion (FBC) wastes, (2) an assessment of the characteristics of leachates generated from the wastes under laboratory and field (landfill) conditions, (3) a characterization of the attenuation of the leachates by earth materials that are typical of disposal settings, (4) development of a way to predict the leachate generation behavior of FBC wastes under landfill conditions on the basis of laboratory test results by establishing a rigorous statistical relationship between the laboratory and field leaching results, and (5) assessment of the compatibility of commonly used landfill liner materials with FBC waste leachates. FBC is an emerging energy technology that holds promise for both high efficiency of energy conversion and minimization of adverse air quality impacts. A major advantage of FBC is that high-sulfur coal can be burned without the use of flue gas desulfurization equipment to meet air quality standards. The solid residues that are generated in an FBC unit are usually larger in volume and have different properties than the typical bottom ash from a conventional boiler.

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NOTE: In some cases, lengthy tables and large groups of figures in this appendix are removed from the text and included as attachments to minimize interruption of the flow of the text.

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D.1 Overview

Laboratory studies of the leaching and attenuation behavior of FBC wastes were designed to develop methods of "scaling up" from laboratory batch equilibration tests to leachate generation and attenuation phenomena observed in field disposal cells. The field cells were designed to simulate actual disposal conditions expected for the FBC wastes (see Appendix E). Appendix G presents the results of attempts to relate statistically the results of the lab and field investigations.

The initial approach was to evaluate the leaching characteristics of the waste materials through a sequence of equilibrium batch extractions in the laboratory. Since the mass of solids and cumulative extraction volumes were known, the data were presented in terms of either concentration versus increasing eluant contact volume per unit mass contacted or cumulative mass extracted per unit mass of solids versus increasing contact volume per unit mass contacted. Different patterns were observed depending upon the controlling mechanism of release into solution, whether it was solubility or sorption (ion exchange) partitioning.

The laboratory protocol consists of six related steps, three steps to characterize the leaching behavior of one waste and three steps to characterize the attenuation behavior of leachate when exposed to a disposal medium. The second and third steps for the waste and the fifth and sixth steps for the medium were repeated until minimal changes in leaching or attenuation were observed. Steps 1 and 2 corresponded to the direct leaching of waste solids, whereas Step 3 related to the case where fluid already equilibrated with solids in the upper portion of a waste column came into contact with fresh waste in a lower portion of the column.

A precept of chromatographic theory, equilibrium partitioning, was the conceptual base for relating batch attenuation studies in the laboratory to field cell behavior. Steps 4 and 5 in combination represented repeated contact of a single mass of disposal medium with fresh leachate (from Step 1) to evaluate the cumulative uptake capacity of the medium. Step 6, also an attenuation procedure, involved addition of fresh soil to the liquid (leachate) phase from a previous attenuation step. Step 6 repetitions simulated the flow of leachate through a soil column.

During development of the procedures for the studies, the literature was searched for tests already developed and in current use (References D-1, D-2, D-3 and D-4). The results of the literature search and preliminary shake tests conducted on FBC wastes for this program were used to develop the procedures for the shake tests and to determine the most significant variables.

The procedures for each step in the leaching and attenuation protocol are detailed in the following sections. The procedures are basically the same for wastes and disposal media. In addition to the multistep protocol Steps 1 through 6, an auxiliary step designated as Step 7 was used during the initial development of the protocol. Step 7, which is described below, was not used as a regular part of the studies.

As noted in Appendix A, the major wastes investigated were Exxon PFBC wastes, Alliance AFBC waste and Georgetown AFBC waste. The attenuating disposal media investigated were shale, coal mine interburden, sandstone, glacial till, alluvium, and limestone.

A common characteristic of all three FBC waste leachates from the laboratory protocol was high values of calcium and sulfate, 1300 to 1600 mg/L and 1100 to 1400 mg/L, respectively, on the average. High pH, total dissolved solids, and conductivity were also obtained on the initial leachates. These characteristics generally persisted with continued extraction. Behavior was quite similar to that of an FGD sludge.

Trace metals and other species were typically much reduced in concentration and varied with the waste leached. Leachate concentrations varied with extraction step, although not always in declining fashion, and the trends were not always consistent from waste to waste for a given species.

Waste solids chemical composition was not always directly related to solution concentration or the total percentage of initial solids content that was leached upon multiple leaching steps. Some general trends were indicated but considerable variability was seen. For example, cumulative extractions of 8.1, 17.3, and 23.8% were obtained for sodium for the three wastes after eight sequential leaching steps. Calcium extractions ranged from 26 to 39%.

Increased solid-to-liquid ratios obtained by repeated contact of the same leaching fluid with fresh waste solids generally led to successively increasing species concentration although occasional declines in concentration were observed. Cumulative percent extractions were typically not constant but rather declined with successive exposure to fresh solids. For example, sulfate decreased from 4.5% of solids content leached for Step 3-1 to 1.3% for Step 3-6 with the Alliance AFBC waste. Potassium, on the other hand, was relatively constant in fraction leached on six successive leachings of fresh solids.

While duration of solid-liquid contact time has been considered to be important in leaching studied, comparison of results for one-, two-, and seven-day leaching times did not produce consistent increases in leachate concentrations with increased contact time. In some cases, decreases were observed instead.

Batch and column leaching results for the disposal media were obtained for comparison to waste leachate behavior. Laboratory columns were intended to serve as baseline comparison for field cell studies (reported in Appendix E). While some elements were leached in greater concentration from certain media in batch leachings (magnesium, manganese, and silicon principally in much greater amounts, zinc to a lesser extent), many elements had concentrations in waste leachates only a factor of two or less greater than the concentrations in the media leachates. Soil column leachate concentrations were generally much higher than the corresponding soil batch leachate concentrations. However, different effective volume-per-mass ratios were represented by the two systems.

Use of selected soil leachates as leaching fluid for the Alliance AFBC waste resulted in reduction of magnesium, manganese, and total inorganic carbon concentrations. Other species were contributed by the waste solids.

RCRA Extraction Procedures performed on all three FBC wastes yielded leachates that did not exceed any RCRA standard. Extractions by the RCRA method yielded higher leachate concentrations for many species than leaching by distilled water. However, a number of species behaved in opposite fashion.

Batch attenuation/mobilization studies for leachates from the three wastes with six disposal medium types yielded results that depended upon both the waste and the medium for many species, even with the first attenuation step. Some species, notably calcium and sulfate, were consistently reduced upon contact with all media and for all wastes. Furthermore, the fractional attenuation was relatively constant for each species across waste and disposal medium type. Similar consistency was found for other species, but lack of consistency was also seen for many others. Much less consistency was obtained for repetitions of the process, both new waste leachate with the same medium and fresh medium with the same leachate.

Laboratory leaching columns of waste and selected disposal media were operated to provide volume-per-mass data in the range not represented by the laboratory batch systems (which are at the high end) and the field systems (which are at the low end).

Special studies were designed to evaluate aspects of experimental design. It was found that centrifugation was acceptable for sample solids removal as compared to filtration. Significant differences were found for initial batch leaching concentrations when results with ground and unground waste were compared. A trend toward lower concentrations resulting from ground waste for some species was indicated. Typically, these species were those present in lower concentrations. An opposite effect was indicated for calcium and sulfate. Included in the special studies was a limited laboratory leaching column study designed to examine the differences observed between laboratory batch extraction results and field cell leachate behavior.

The leachate concentration data are given in Appendix J. The solid sample analysis results are given in Appendix C.

D.2 Components of the Laboratory Investigation

The individual components of the laboratory studies are presented in detail in the following sections.

D.2.1 The Batch Equilibration Procedure

The central component of the laboratory studies was a six-step batch equilibration protocol. The leaching potential of FBC solid residues and the chemical behavior of FBC leachate when exposed to various disposal media were evaluated from the results of these batch equilibration ("shake") tests. These tests included extractions of the FBC wastes and disposal media with appropriate solutions at a constant agitation rate. Major and minor chemical components in the extraction leachates were monitored to define trends in chemical behavior during leachate generation and attenuation. This behavior was monitored to determine both primary and secondary effects in leaching and attenuation.

D.2.1.1 The Six Step Protocol

The multi-step sequence of the shake tests is summarized diagrammatically in Figure D-1. For descriptive purposes in regard to the figure, the following legend applies:

△1 – Step 1, Initial Leaching from Waste

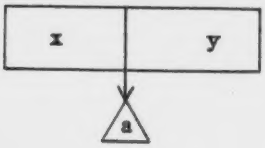
△2 – Step 2, Secondary Leaching of "Leached" Waste with Fresh Water

△3 – Step 3, Secondary Exposure of Leachate to Fresh Waste

△4 – Step 4, Initial (Primary) Attenuation/Mobilization of Waste Leachate by a Solid Disposal Medium

△5 – Step 5, Secondary Attenuation/Mobilization by Burdened Disposal Media in Contact with Fresh Leachate

△6 – Step 6, Secondary Attenuation/Mobilization of Leachate by Fresh Disposal Medium



Denotes solid phase "x" in contact with liquid phase "y" and taken through Step "a" in the protocol.

During development of the protocol, it was assumed that the disposal media would remove (attenuate) contaminants from the leachate. However, it was found that in some cases certain species were contributed by the disposal media, Hence, the term "attenuation/mobilization" is used instead of "attenuation" to describe the interaction of leachate and disposal media. The shorter term "attenuation" is used in the text. Each of the steps in the protocol is described below with the information needed to set up that particular step.

D.2.1.1.1 Step 1 - Initial Leaching

FBC waste was leached with deionized water to measure primary or initial leaching in this step. The solid and liquid phases were equilibrated for one day, two days and seven days to define the rate and extent of

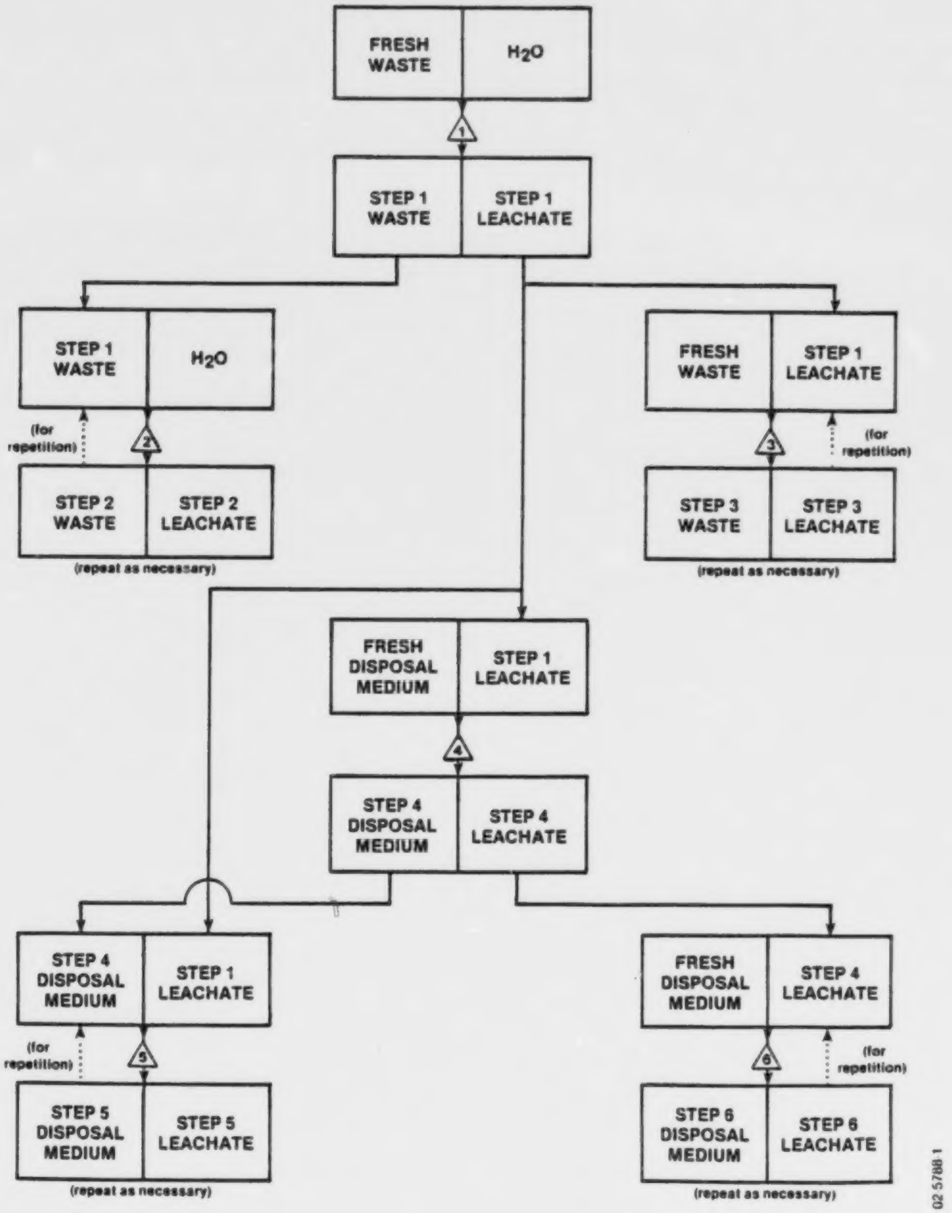

FRESH WASTE
H_2O
1
STEP 1 WASTE
STEP 1 LEACHATE
STEP 1 WASTE
H_2O
(for repetition)
2
STEP 2 WASTE
STEP 2 LEACHATE
(repeat as necessary)
FRESH WASTE
STEP 1 LEACHATE
3
(for repetition)
STEP 3 WASTE
STEP 3 LEACHATE
(repeat as necessary)
FRESH DISPOSAL MEDIUM
STEP 1 LEACHATE
4
STEP 4 DISPOSAL MEDIUM
STEP 4 LEACHATE
STEP 4 DISPOSAL MEDIUM
STEP 1 LEACHATE
(for repetition)
5
STEP 5 DISPOSAL MEDIUM
STEP 5 LEACHATE
(repeat as necessary)
FRESH DISPOSAL MEDIUM
STEP 4 LEACHATE
6
(for repetition)
STEP 6 DISPOSAL MEDIUM
STEP 6 LEACHATE
(repeat as necessary)
02 5788 1

Figure D-1. Laboratory Batch Equilibration Protocol for FBC Waste Leaching and Leachate Attenuation.

leaching. Only seven-day leachates or leached solids were carried forward to succeeding steps. No pH control was used. Multiples of this step were run in order to measure repeatability and to generate enough leachate and leached solids for subsequent steps.

After the required equilibration period, the solid and liquid phases were separated by high-speed centrifuge or by filtration. The leachates were analyzed or carried forward to Step 3 or Step 4. The solids were carried forward to Step 2 or discarded.

D.2.1.1.2 Step 2 - Secondary Leaching with Eluant Replacement

During Step 2, solids initially leached for seven days in Step 1 were subjected to additional leaching by fresh eluant (deionized water). This step was designed to correspond with leaching behavior in field conditions when replacement volumes of liquid pass through solid residues after initial leaching. Step 2 leachates were equilibrated for seven days.

After the equilibration period, the solid and liquid phases were separated, and the leachates were analyzed. The solids were carried forward for repetition of the step. The process was repeated several times in an attempt to reach a point where little or no additional leaching was occurring when fresh eluant was placed on the previously leached waste. Leachate from each of the repetitions was analyzed. After the equilibration period of the final repetition of Step 2, samples of the residual solids were analyzed. The results of the solid sample analyses are reported in Appendix C.

D.2.1.1.3 Step 3 - Secondary Leaching with Waste Replacement

Leachate that had been initially equilibrated for seven days in Step 1 was placed in contact with fresh unleached waste during Step 3. This step was designed to measure the extent to which leachate will continue to take up key species as it percolates and encounters fresh waste under field conditions. This step also allowed determination of whether or not a given species was in a condition of saturation with regard to secondary leaching. Step 3 leachates were equilibrated for seven days.

After the required equilibration period, the solid and liquid phases were separated. The leachates were analyzed or carried forward for repetition of the step. The solids were discarded.

To repeat Step 3, sufficient samples were set up initially to provide the necessary eluant for the desired number of repetitions. At the end of each repetition, the leachate from two samples was analyzed, and the remainder of the leachates were composited to provide eluant for the next repetition with fresh unleached solids. The solids, as previously mentioned, were discarded. Figure D-2 illustrates the steps necessary to provide six repetitions of the step.

D.2.1.1.4 Step 4 - Initial Attenuation/Mobilization by a Disposal Medium

In Step 4, leachate that had been initially equilibrated for seven days in Step 1 was placed in contact with a disposal medium for one, two and seven days. Step 4 was performed separately for each of the six disposal media. This step was designed to measure the attenuating capacity of each medium and to allow comparisons among the six different media. Analysis of the leachate at the three time intervals permitted the determination of both the rate and extent of attenuation.

After the required equilibration period, the solid and liquid phases were separated. The leachates were analyzed or carried forward to Step 6. The solids were carried forward to Step 5 or discarded.

D.2.1.1.5 Step 5 - Secondary Attenuation/Mobilization by Burdened Disposal Media in Contact with Fresh Leachate

During Step 5, solids from Step 4 that were previously exposed to Step 1 leachate for seven days were placed in contact with additional leachate from Step 1. This step was designed to measure the capacity of the disposal

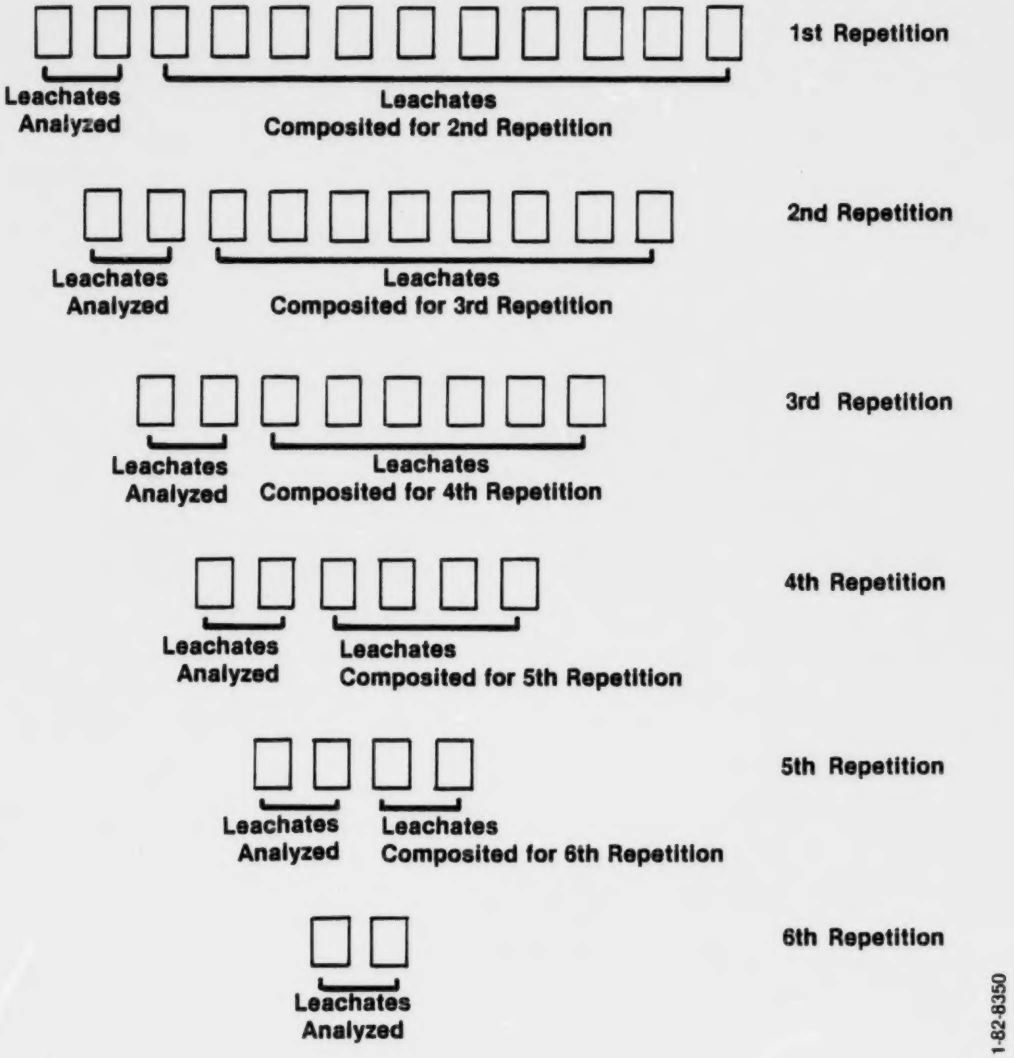

1st Repetition
Leachates Analyzed
Leachates Composited for 2nd Repetition
2nd Repetition
Leachates Analyzed
Leachates Composited for 3rd Repetition
3rd Repetition
Leachates Analyzed
Leachates Composited for 4th Repetition
4th Repetition
Leachates Analyzed
Leachates Composited for 5th Repetition
5th Repetition
Leachates Analyzed
Leachates Composited for 6th Repetition
6th Repetition
Leachates Analyzed
1-82-8350

Figure D-2. Scheme for Successive Leaching with Replacement of Solids in Steps 3 and 6 of the Protocol.

media to bring about additional attenuation (or mobilization) when exposed to fresh leachate.

After the seven-day equilibration period, the solid and liquid phases were separated, and the leachates were analyzed. The solids were carried forward for repetition of the step. This process was repeated for a fixed number of steps with the intent of reaching the point where no significant attenuation was occuring. After the final repetition of Step 5, samples of the residual solids were also analyzed (see Appendix C).

D.2.1.1.6 Step 6 - Secondary Attenuation/Mobilization of Leachate by Fresh Disposal Medium

In Step 6, leachates that had been initially equilibrated for seven days in Step 4 were placed in contact with fresh unleached disposal media. This step was designed to determine incremental (secondary) attenuation or mobilization. After the seven-day equilibration period, the solid and liquid phases were separated. The leachates were analyzed or carried forward for repetition of the step. The solids were discarded.

To repeat Step 6, sufficient samples were set up initially to provide the necessary eluant for the desired number of repetitions. At the end of each repetition, the leachate from two samples was analyzed, and the remainder of the leachates were composited to provide eluant for the next repetition (the solids were discarded) with fresh unleached solids. Figure D-2 illustrates the steps necessary to provide 5 repetitions of the step. The first repetition is actually Step 4.

D.2.1.1.7 Step 7 - Secondary "Leaching" from a Burdened Disposal Medium in Contact with Fresh Water

During the initial development of the laboratory protocol, an additional step, Step 7, was evaluated. This step was later replaced with the step later designated as Step 5. Initially, Step 7 was considered an auxiliary step but it was not used as a regular part of the studies.

Solids from Step 4, which were previously in contact with Step 1 leachate for seven days, were placed in contact with deionized water. This step was designed to determine whether an attenuating disposal medium which has incorporated species from leachate by surface adsorption, precipitation, ion-exchange and other processes will release these species to fresh water at a later time. The tendency for "re-release" was determined by conducting equilibrations for both one day and seven days with "burdened" media from Step 4. This procedure was intended to give a measure of the tendency of the medium to "desorb" a species into fresh eluant.

After the equilibration period, the solid and liquid phases were separated. The leachates were analyzed and the solids were carried forward for repetition of the step. The procedure was repeated by sucessive replacement of fresh water to determine when a steady state had been reached in regard to continued "desorption".

D.2.1.2 Fixed Variables of the Protocol

Variables that were considered in the development of the shake test were: (1) time of agitation and leaching; (2) solid-to-liquid ratio; (3) nature of leaching liquid phase (e.g., pH); and (4) method of agitation. Based upon the results from the preliminary studies for this program and the results from other leaching tests found in the literature, the following basic procedure was formulated:

(1) the initial (Step 1) extracting liquid phase (eluant) was deionized water;

(2) the extraction times were one day, two days, and seven days;

(3) the solid-to-liquid mass ratio was 1:10 (25g solid to 250 mL H_2O) in order to minimize common ion and solution nonideality effects for species of interest;

(4) all wastes and disposal media were ground to obtain uniform particle size in order to insure homogeneity of wastes and reproducibility (the effect of grinding was evaluated in this study and is reported below);

(5) continuous solid and liquid agitation was maintained on a rotator at constant specified parameters to ensure maximum contact with minimum particle abrasion;

(6) the containers were air-tight, so no carbon dioxide exchange with the atmosphere occurred during agitation.

D.2.1.3 Protocol Preparation and Operation

The materials and apparatus were prepared before the laboratory studies were initiated. These initial preparations were important since they, in part, set the conditions of the study. They included solids preparation, leachate container preparation, and mixing apparatus preparation.

D.2.1.3.1 Solids Preparation

Solids (wastes and disposal media) were prepared so as to ensure that the samples were both representative and reproducible. A sufficient quantity necessary for completion of the entire study was prepared initially so that small batches did not have to be prepared as the study progressed. Approximately 10 kilograms of waste and one kg of disposal medium were required to carry out the entire protocol (Steps 1 through 6) for each combination of waste and disposal medium. In general, solids preparation included two or more of the following steps: 1) coning and quartering; 2) crushing; 3) drying; 4) grinding; and 5) mixing.

Coning and quartering were necessary because a representative sample of a large quantity of material had to be obtained. The method chosen to accomplish this objective was to pour the material onto a large plastic sheet placed on the floor and use a metal yard stick to separate the pile into four equal portions. This process was repeated until the amount of material needed was obtained.

Crushing was necessary when the material contained many clods or peds which were too large to be put through the grinder. The disposal media contained chunks two to three inches in diameter. The simplest method of breaking up these chunks was to place them between two pieces of heavy plastic and fracture them with a heavy mallet.

The samples were dried primarily to make the grinding process easier. A drying temperature of 50°C was used to prevent alteration of the sample; higher temperatures could remove waters of hydration and result in different leaching characteristics. The solids were spread out in shallow layers so that a drying period of 24 hours was sufficient.

Since the amount of solid used in each leaching container was small (25 g), the solids were ground prior to leaching in order to obtain a reproducible and representative sample in each test. Sample grinding was done in a grinder manufactured by BicoBraun Instruments, Inc. (Model 242-79A), which has porcelain grinding plates and a teflon coated feed and collection chamber. This type of grinder was used to limit contamination of the solids with metal from the grinder. No effort was made to obtain a particular particle size, but the resulting solids were approximately 100-200 mesh.

Solids were mixed to the extent necessary to obtain a homogeneous sample. If several components were needed, they were mixed after grinding. For example, for the Exxon PFBC waste, three components were mixed in the proportions that engineering data indicated the wastes are produced during plant operation (see Appendix A).

For mixing purposes, a roller type jar mill manufactured by Norton (Model 753-RM) was used since it accommodated a relatively large sample. Because additional grinding of the solids was not desired, only a few of the ceramic stones were used and the mixing time was limited to 20-30 minutes.

D.2.1.3.2 Leachate Container Preparation

The containers used in the leaching studies were 250 mL polypropylene centrifuge containers (International Equipment Company No. 2050) manufactured for the centrifuge used in the solid/leachate phase separation. The containers were soaked overnight in a 1:5 dilution of concentrated nitric acid, rinsed with several portions of deionized water and filled to capacity with deionized water for storage until needed. Just prior to use, the deionized water was emptied out and the container was given one last deionized water rinse. This process was considered adequate for removal of any trace contaminants present from the manufacture and handling of the containers.

Sufficient containers were provided to minimize reuse, although containers were occasionally reused when a step was repeated or the same materials were used in a different step. When the bottles were reused for the same step (as in generation of Step 1 leachates), the container was emptied of residual solids and rinsed several times with deionized water. When the bottles were reused with the same materials (Step 4 or 5 succeeded by Step 6), the initial nitric acid soak and deionized water rinse was repeated.

D.2.1.3.3 Mixing Apparatus Preparation

The Rugged Rotator, manufactured by Kraft Apparatus, Inc. (Model RD-250), was used for agitation of the leachates. This apparatus provided good mixing of the solid and liquid phases without abrasion of the solids. This mixer has a head with an adjustable angle of incline and a variable speed control. For the purpose of this study, the incline of the head was adjusted to an angle of approximately 70° to the horizontal which resulted in an end-over-end action of the leachate within the container. The speed of rotation was set at approximately six rpm.

The angle on the head was set using a protractor and a plumb line. The protractor was placed against the plane of the head and the head was adjusted to 20° angle to the plumb line, resulting in a 70° angle to the horizontal. The container clamps were positioned in the head so that the long axis of each of the containers was parallel to the plane of the head.

The speed of rotation was determined by placing a marker on the head and counting the number of rotations it made in a time period measured with a stop watch. The control was then adjusted to increase or decrease the speed, and the process was repeated until the approximately six rpm speed was achieved. When the speed of rotation was adjusted, the agitator was loaded with the leachates, since the speed varied with the total mass on the mixer.

Leachates were kept under continuous agitation for the leaching period. Seven-day leaching periods were generally used to ensure that equilibrium or steady state conditions had been obtained. However, in Steps 1 and 4 leaching periods of one and two days were utilized in addition to the seven day period for purposes of evaluating the rate of leaching (Step 1) or attenuation/mobilization (Step 4).

After the equilibration period, the solid and liquid phases of the sample were separated and one or both of the phases were preserved as appropriate for chemical analysis. The takedown operations consisted of the following: 1) separation of the solid and liquid phases; 2) preparation and preservation of leachates for chemical analysis; 3) preparation and preservation of residual solids for chemical analysis; and 4) labeling and correlation of leachates and solids.

The solid and liquid phases of the samples for the Exxon PFBC and Alliance AFBC wastes were separated by centrifugation in a high-speed centrifuge, manufactured by Damon/International Equipment Company (Model B-20A). Less solids were carried over with the leachate when an initial settling period was used prior to centrifugation. During the settling period (after there was clear supernatant at the top of the container), the container was gently rocked to allow the liquid to wash down any remaining solids adhering to the cap and neck of the container. The samples were then centrifuged at approximately 2500 rpm for a period of 20 minutes. The leachate was then decanted directly into sample containers (60 mL polypropylene bottles).

D.2.1.3.4 Protocol Setup and Takedown

During setup, solids were weighed out on a top-loading balance. A mass of 25 ± 0.5 g was weighed into a plastic weighing boat and then carefully transferred to a 250 mL leaching container. A volume of 250 mL of eluant was measured out into a graduated cylinder, a portion of this amount was added to the leaching container, and the container was swirled to wet the solids. The remainder of the eluant was carefully added to the container and the cap was tightened down. (Note: these steps were necessary since the solids and liquids fill the container to capacity.) The containers were then loaded onto the mixing apparatus, the weight across the head was balanced, and the speed of rotation was set at six rpm.

When one or both of the phases were carried forward it was necessary to make adjustments to maintain the 1:10 solid/liquid ratio. Approximately 20 mL of the original liquid remained with the solids after separation of the phases. Therefore, when the solids were carried forward, as in Steps 2 and 5, only 230 mL of eluant were added (more than this amount would overflow the containers). When the leachates were carried forward, as in Steps 3 and 6, the amount of leachate available had decreased. Therefore, in order to maintain the 1:10 ratio, less fresh unleached solids were used.

The sample preservation containers were placed (without lids) so that the centrifuged leachate could be poured into the containers in one smooth operation without having to set down the centrifuge container between sample splits. When the sample was set down between pouring into each container, the action of the liquid across the solids in the bottom of the container often caused a portion of the solids to rise back into the liquid phase.

For the reduced protocol study on Georgetown AFBC waste (Steps 1, 2, and 4 as described below), the samples were subjected to membrane filtration (0.45 μm) after centrifugation.

The leachates were split into four aliquots at the time of separation of the solid and liquid phase. Each of the aliquots was preserved as appropriate for the chemical analysis to be done. The preservation techniques used are shown in Figure D-3.

The residual solids remaining in the leachate container were removed with a spatula and placed in a clean beaker or porcelain boat. As much of the material was removed as possible in order to maintain a representative sample. The solids were oven dried overnight at 50°C and were cooled in a desiccator. Once the solids were dried and cooled, they were ground with a mortar and pestle, placed in a clean container, and labeled to correlate with the corresponding leachate. The coding used for the labeling of samples is described in Section D.2.6. No additional sample preservation steps were necessary.

D.2.1.3.5 Repetition of Protocol Steps

The selection of initial parameters of analysis is described in Appendix A. Each waste was evaluated individually and key species of interest were selected as the study progressed. It was expected that compounds of primary importance in one waste would not have the same degree of importance in another waste. There were no established methods to predict in advance the number of repetitions necessary for the different steps of the laboratory leaching protocol. A fairly complete initial set of data for the original solids and the Step 1 leachates would have been helpful to make a judgement in the species of interest and the number of repetitions required. But due to cost effectiveness of analyses, these data did not become available until later in the studies. Therefore, the approach chosen was to repeat each step at least six times (five times for Step 6) and, if necessary after evaluating the initial data, to repeat for as many as a total of nine times for Steps 2 and 5.

For the leaching studies of Exxon PFBC waste, concentrations of calcium and sulfate in the leachates were used as the determinative factors governing the progression of repetitions. In later studies more parameters were

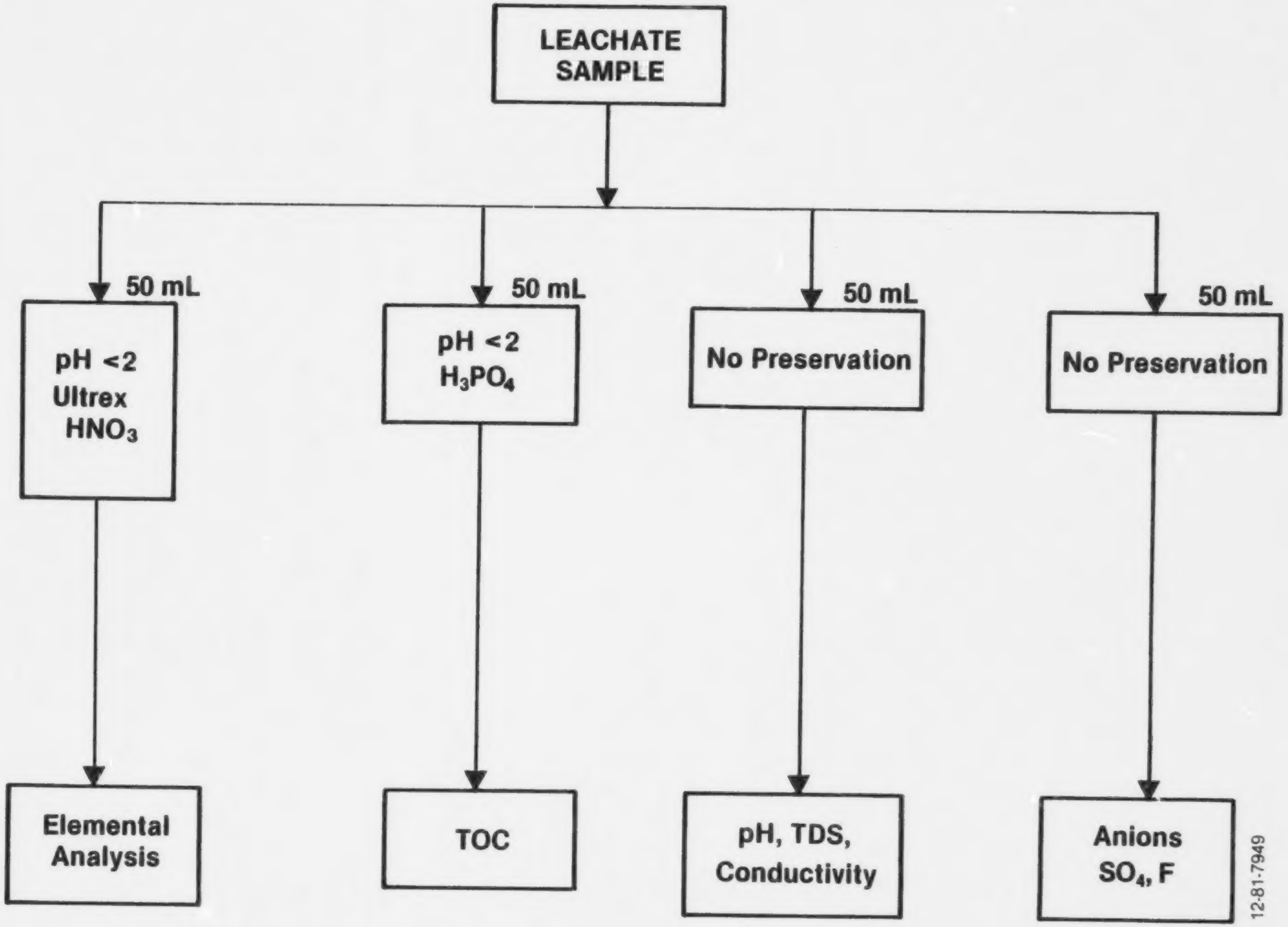

LEACHATE SAMPLE
50 mL
pH <2 Ultrex HNO3
50 mL
pH <2 H3PO4
50 mL
No Preservation
50 mL
No Preservation
Elemental Analysis
TOC
pH, TDS, Conductivity
Anions SO4, F
12-81-7949

Figure D-3. Preservation Procedures for Laboratory Leachate Samples.

used for this evaluation. This expanded examination was necessary for evaluation of the "total" leaching capacity of the wastes or "total" attenuation capacity of the disposal media when these were differences in behavior among major and minor components.

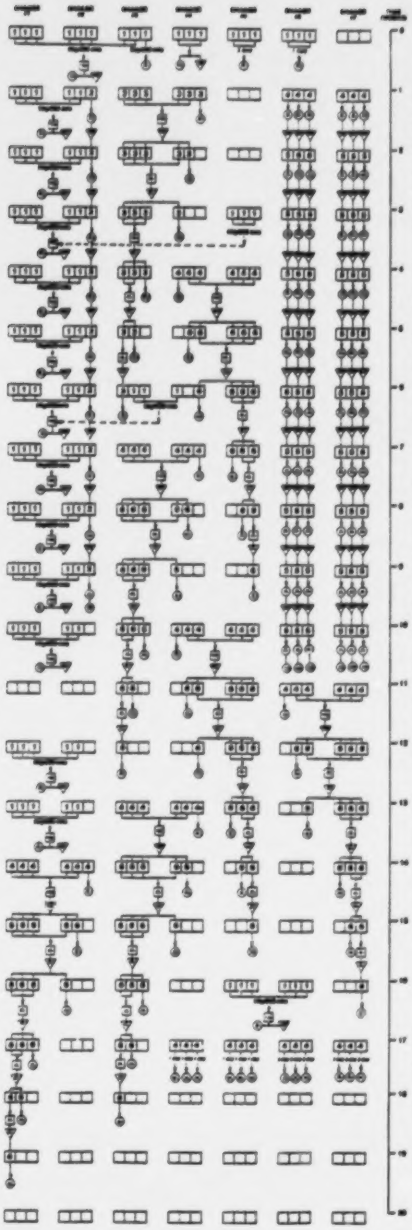
D.2.1.3.6 Scheduling the Protocol

The implementation of the laboratory protocol was a matter of planning and scheduling each step considering the equipment available, the leaching time requirement, and the sequential relationship of one step to another. Steps 1 and 4 were the two pivotal points of the protocol since at least one of these steps was necessary before the succeeding steps could be initiated. Step 1 leachate was generated on a weekly basis to provide the required eluant for Steps 3, 4, 5 and 6 of the protocol.

Figure D-4 illustrates a typical scheduling plan for Steps 1 through 6 of the protocol for one waste and six disposal media. This figure shows on a weekly basis the steps in operation in each of the seven shakers available. Unless noted, all leachates were conducted using 25 g of solid and 250 mL of eluant with a seven-day leaching period. The symbols following arrows ( ) denote final disposition of phases at the end of a time period. At the far right of the figure, a sample summary for the Exxon PFBC waste is given which lists the numbers and types of leachates generated for each seven-day period, the approximate amount of Step 1 leachate generated, and any new steps to be initiated. Sample identification code numbers represented in the summary of operations are explained later in Section D.2.6. This figure was also used to predict the amount of time needed each week to set up and take down the tests and to perform the analyses.

D.2.2. Batch Leaching Studies Conducted (Steps 1, 2, and 3 of the Protocol)

Most of the batch leaching studies were performed on three FBC wastes and the six disposal media selected for the program (see Appendix A). In addition, studies were performed to evaluate sample representativeness, the



SUMMARY OF OPERATIONS

Initiate Step 1 for Waste 1

Samples for analysis: 20 total
6-L110100, 6-L120100, 6-L170100, 2-L170100*
Step 1 leachate generated: 7.5 liters
Initiate Steps 2, 3 and 4 (all six disposal media)

Samples for analysis: 18 total
2-L170100*, 2-L271100, 2-L371100, 2-L470108, 2-L470109, 2-L470110, 2-L470112,
2-L470113, 2-L470114
Step 1 leachate generated: 4 liters
Initiate Step 5 for all six disposal media

Samples for analysis: 18 total
2-L170100*, 2-L272100, 2-L372100, 2-L571108, 2-L571109, 2-L571110, 2-L571112,
2-L571113, 2-L571114
Step 1 leachate generated: 4 liters
Samples for analysis: 18 total
2-L170100*, 2-L273100, 2-L373100, 2-L572108, 2-L572109, 2-L572110, 2-L572112,
2-L572113, 2-L52114
Step 1 leachate generated: 7 liters
Initiate Step 4 carry to Step 6 for disposal medium #08
Samples for analysis: 20 total
2-L170100*, 2-L274100, 2-L374100, 2-L573108, 2-L573109, 2-L573110, 2-L573112,
2-L573113, 2-L573114, 2-L470108

Samples for analysis: 20 total
2-L170100*, 2-L275100, 2-L375100, 2-L574108, 2-L574109, 2-L574110, 2-L574112,
2-L574113, 2-L574114, 2-L671108
Step 1 leachate generated: 4 liters

Samples for analysis: 20 total
2-L170100*, 20L276100, 2-L376100, 2-L575108, 2-L575109, 2-L575110, 2-L575112,
2-L575113, 2-L575114, 2-L672108
Step 1 leachate generated: 7 liters
Initiate Step 4 Step 6 for disposal medium #09

Samples for analysis: 20 total
2-L170100*, 2-L277100, 2-L576108, 2-L576109, 20L576110, 2-L576112, 2-L576113,
2-L576114, 2-L673108, 2-L470109
Step 1 leachate generated: 4 liters

Samples for analysis: 20 total
2-L170100*, 2-L278100, 2-L577108, 2-L577109, 2-L577110, 2-L577112, 2-L577113,
2-L577114, 2-L674108, 2-L671109
Step 1 leachate generated: 4 liters
Samples for analysis: 22 total
2-L170100*, 2-L279100, 2-L578108, 2-L578109, 2-L578110, 2-L578112, 2-L578113,
2-L578114, 2-L675108, 2-L672109, 2-S279100
Step 1 leachate generated: 4 liters
Initiate Step 4 Step 6 for disposal medium #10
Samples for analysis: 30 total
2-L170100*, 2-L579108, 2-L579109, 2-L579110, 2-L579112, 2-L579113, 2-L579114,
2-L673109, 2-L470110, 2-A579108, 2-A579109, 2-A579110, 2-A579112, 2-A579113,
2-A579114; Initiate Step 4 Step 6 for disposal medium #12
Samples for analysis: 6 total
2-L674109, 2-L67110, 2-L470112

Samples for analysis: 8 total
2-L170100*, 2-L675109, 2-L672110, 2-L671112
Step 1 leachate generated: 4 liters
Initiate Step 4 Step 6 for disposal medium #13
Samples for analysis: 8 total
2-L170100*, 2-L673110, 2-L672112, 2-L470113
Step 1 leachate generated: 4 liters
Initiate Step 6 Step 6 for disposal medium #14

Samples for analysis: 8 total
2-L674110, 2-L673112, 2-L67113, 2-L470114

Samples for analysis: 8 total
2-L675110, 2-L674112, 2-L672113, 2-L671114

Samples for analysis: 8 total
2-L170100*, 2-L675112, 2-L673113, 2-L672114
Step 1 leachate generated: 5 liters
Initiate 1 day, 2 day Step 4 rate studies for each of the 6 disposal media
Samples for analysis: 28 total
2-L674113, 2-L673114, 2-L410108, 2-L410109, 2-L410110, 2-L410112, 2-L410113,
2-L410114, 2-L420108, 2-L420109, 2-L420110, 2-L420112, s-L420113, 2-L42011 4

Samples for analysis: 4 total
2-L675113, 2-L674114

Samples for analysis: 2 total
2-L675114

Laboratory Protocol Summary

Step 1 - FBC waste in contact with deionized water.

Step 2 - Solid residue of waste from Step 1 in contact with fresh deionized water.

Step 3 - Step 1 leachate in contact with fresh solid waste.

Step 4 - Step 1 leachate in contact with disposal medium.

Step 5 - Solid residue of disposal medium from Step 4 in contact with Step 1 leachate.

Step 6 - Leachate from Step 4 in contact with fresh disposal medium.

Legend

1 1 1	Denotes the six positions on each shaker; each block indicates two positions since all extractions are done in at least duplicates. The number within the block indicates the step in the protocol.
Ⓐ	Denotes that a phase is to be analyzed. In this case, two leachate phases are to be analyzed.
□	Denotes that a phase is to be composited.
▽	Denotes that a phase is to be carried forward for repetition or to another step.
L	Denotes the leachate phase.
S	Denotes a solid residue of a waste.
A	Denotes a solid residue of a disposal medium.

Figure D-4. Scheduling Plan for the Batch Equilibration Protocol.

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effects of sample grinding, the effects of sample filtration, and other experimental parameters.

D.2.2.1. Extraction of Wastes

The extraction steps of laboratory protocol (Steps 1, 2, and 3) were performed on three FBC wastes and one waste from a coal-fired power facility. These wastes are as follows: 1) Exxon PFBC waste; 2) Alliance AFBC waste; 3) Georgetown AFBC waste; and 4) Huntington flue gas desulfurization (FGD) waste. Appendix A contains a detailed description of the individual wastes studied. A brief description of the source and composition of each waste is presented below. The labeling scheme used to identify leachates generated from these wastes is described in Section D.2.6.

D.2.2.1.1 Exxon PFBC Waste

The Exxon PFBC waste studied in the laboratory and field was a mixed material from runs 79, 80, and 81 at the Exxon PFBC Miniplant, Linden, New Jersey. The solid sample chemical compositions of the PFBC feed coal and feed dolomite, the PFBC component wastes and waste composites, and raw and leached (after seven repetitions of Step 2) PFBC waste are described in Appendix C.

D.2.2.1.2 Alliance AFBC Waste

The Alliance AFBC waste was obtained from the EPRI/Babcock & Wilcox 6' x 6' AFBC pilot plant at Alliance, Ohio, while the pilot plant was operating in a recycle mode. The solid sample chemical composition of raw and leached (after nine repetitions of Step 2) Alliance AFBC waste is described in Appendix C.

D.2.2.1.3 Georgetown AFBC Waste

The second AFBC waste was obtained from the DOE/Georgetown University AFBC boiler. The chemical composition of the raw and leached (after seven repetitions of Step 2) Georgetown AFBC waste is listed in Appendix C.

D.2.2.1.4 Huntington FGD Waste

The Huntington flue gas desulfurization (FGD) waste was obtained from the Utah Power and Light Huntington Plant. The component wastes used resulted from the combustion of coal mined in the vicinity of the power plant. The Huntington waste was formed by mixing one part fly ash with one part scrubber sludge. The solid sample compositions of both component wastes are reported in Appendix C.

D.2.2.1.5 Extraction Steps Conducted for Each Waste

Table D-1 depicts the total extraction matrix for the four wastes. Full seven-day extraction protocols were conducted on the Exxon PFBC and Alliance AFBC wastes. Steps 1 and 2 were conducted on the Georgetown AFBC waste. The Huntington FGD waste was subjected to Step 1 extraction. One-day and two-day extractions were performed on the Exxon PFBC and Alliance AFBC wastes.

D.2.2.2 Extractions of Disposal Media

The six disposal media used in the attenuation steps of the protocol (Steps 4, 5 and 6) were also subjected to deionized water leaching (Steps 1 and 2). The intent of these extraction studies was to evaluate the nature and amount of species that could be contributed by (mobilized from) the media to the FBC leachate. (As noted, some species in the FBC leachate increased rather than decreased in concentration when the leachate was exposed to the disposal media.) The six media used were shale, coal mine interburden, sandstone, glacial till, alluvium, and limestone. The sources of the

TABLE D-1. SUMMARY OF EXTRACTION STEPS AND REPETITIONS PERFORMED ON THE FOUR FBC WASTES

Step – Repetition	Number of Samples Generated											
	Exxon PFBC			Alliance AFBC			Georgetown AFBC			Huntington FGD		
	1 day	2 day	7 day	1 day	2 day	7 day	1 day	2 day	7 day	1 day	2 day	7 day
Step 1	6	6	8	6	6	36			6	6	6	12
Step 2-1	2		2			2			4*			
2-2	2		2			2			4*			
2-3			2			2			4*			
2-4			2			2			4*			
2-5			2			2			4*			
2-6			2			2			4*			
2-7						2			4*			
2-8						2			4*			
2-9						2			4*			
Step 3-1	2		2			2						
3-2			2			2						
3-3						2						
3-4						2						
3-5						2						

*Includes unground sample extracts.

disposal media are described in Appendix A. The following media extractions were conducted:

1. Early in the experimental program, Step 1 batch leaching (with four replications) was performed on samples of shale, interburden, sandstone, and Greer limestone. (The Greer limestone was subsequently replaced by the Greenbrier limestone in the protocol, see Appendix A).

2. Duplicate Step 1 batch extractions were performed on all six disposal media (Greer limestone was not included since it was replaced by Greenbrier limestone, see Appendix A.)

3. More extensive leaching of two disposal media (shale and sandstone) was conducted. Eight repetitions of the leaching process were performed on each of these media (Step 1 followed by seven repetitions of Step 2).

D.2.2.3 Extraction of Wastes with Leachate from the Disposal Media

As a follow up on the batch extractions of the disposal media, a special Step 1 and Step 2 extraction study was designed. The intent was to evaluate the effect of water passing through an upper layer of soil prior to contacting the waste below (as was the case in the field cells, see Appendix E).

The materials used for this experiment included the Alliance AFBC waste and the shale and sandstone disposal media. Duplicate portions of the waste were initially leached (according to Step 1 procedures) for seven days with leachates derived from Step 1 leaching of both shale and sandstone. After the seven-day equilibration period, the eluant was removed for analysis and the leached waste samples were carried forward into secondary leaching using additional Step 1 leachates from the disposal media. This secondary leaching (Step 2) process was repeated seven times. At the end of the seventh repetition, the solid residue (leached waste) was also retained for solid sample analysis. This experiment generated a total of 32 leachates and four solid samples for analysis. The initial and secondary leachates were coded using a symbolism to indicate that the steps were modifications to the usual protocol. (See Section D.2.6.)

D.2.2.4 RCRA Extractions

The Extraction Procedure (EP) toxicity was determined for unground samples of Exxon PFBC, Alliance AFBC, and Georgetown AFBC wastes by performance of the EP as given in 46 FR 35247, July 7, 1981. These determinations were performed in duplicate for each waste.

In this test, a representative 100 g sample of each waste was extracted with 1.6 liters of distilled water with an initial pH adjustment requiring the maximum allowable acid addition of 400 mL of 0.5 N acetic acid. After 24 hours of mechanical stirring at a controlled constant rate, the suspension was filtered, diluted to 2.0 liters and the filtrate was analyzed for the eight metals specified by RCRA regulations as well as the same chemical species as were determined for the batch protocol leachates.

D.2.3 Batch Attenuation Studies Conducted

Table D-2 presents the total attenuation/mobilization matrix for each of the three FBC wastes. Attenuation behavior was not evaluated for the Huntington FGD sludge extracts. Full Step 4, 5 and 6 attenuation studies were conducted on the Exxon PFBC and Alliance AFBC wastes. Step 4 was carried out on the Georgetown AFBC waste because examination of the results from the first two wastes led to the decision to perform only the first step in the attenuation sequence. The disposal media used are described in detail in Appendices A and B. The labeling scheme used to identify the individual solutions resulting from each step of the protocol is described in Section D.2.6.

During the initial attenuation study (with Exxon PFBC waste), specific analyses were not conducted on the Step 1 composite samples actually used

TABLE D-2. SUMMARY OF ATTENUATION/MOBILIZATION STEPS AND REPETITIONS FOR THE THREE FBC WASTES

Step - Repetition	Number of Samples Generated for Each Disposal Medium*								
	Exxon PFBC			Alliance AFBC			Georgetown AFBC		
	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days
Step 4	2	2	4	2	2	4			2
Step 5-1			2			2			
5-2			2			2			
5-3			2			2			
5-4			2			2			
5-5			2			2			
5-6			2			2			
5-7						2			
5-8						2			
5-9						2			
Step 6-1			2			2			
6-2			2			2			
6-3			2			2			
6-4			2			2			
6-5			2			2			
Step 7-1			2						
7-2			2						
7-3			2						
7-4			2						
7-5			2						
7-6			2						

*Number of samples generated for each of the six disposal media. To obtain the total number of samples generated, multiply each entry by six.

for each of the Step 4 and Step 5 attenuations. Rather, the intent was to use the average analytical values obtained from the Step 1 leachates generated in the Step 1, Step 2, and Step 3 sequence of extractions. It was presumed that the average value would properly represent a large volume composite sample obtained from several Step 1 extractions. During the studies of the Alliance AFBC waste, complete analysis was obtained for each composite used in subsequent steps. Thus, fractional attenuation values (see Section D.7) obtained for the Alliance AFBC waste with the individual disposal media were each calculated from different Step 1 values. For the Exxon PFBC waste, fractional attenuation calculations had to be obtained from an average Step 1 value. The derivation of leachates for Steps 4, 5, and 6 is described further in Section D.2.6.4.

With the reduced protocol used for the Georgetown AFBC waste, only Step 4 was conducted, and specific analyses were obtained for the large-volume composite Step 1 leachates used for the attenuation studies.

Shorter duration "equilibrations" were conducted only for Step 4 and only for the Exxon PFBC and Alliance AFBC wastes. Both one-day and two-day contact times were used.

D.2.4 Laboratory Column Studies

Two laboratory column studies were conducted. The first set of columns contained disposal media only and were intended to back up the field cell study. These laboratory control columns were used to generate a set of media leaching control data. The second laboratory column study (column leaching study) was initiated near the end of the project to close data gaps between the laboratory batch equilibration studies and the field cell investigations.

D.2.4.1 Laboratory Control Columns

In lieu of constructing a complete set of control (media only) cells in the field, a combination of field and laboratory controls was used. The field investigation included two full-size control field cells (see Appendix E). A full set of control columns with all six disposal media was also operated in the laboratory. These columns were six-inch diameter plexiglas cylinders, six feet long, containing a six-inch lift of inert silica sand at the base and a five-foot lift of disposal media. The columns were mounted vertically in wall racks, and sample collection flasks placed under each. Table D-3 shows the contents of the six columns, and the depth of the media after irrigation. The media were poured dry into the columns (not packed) which is analogous to the filling procedures of the field cells. A single porous ceramic cup at the base served as both a bottom drain and sample collection device. The assembly procedure is outlined in Table D-4.

TABLE D-3. CONTENTS OF LABORATORY CONTROL COLUMNS

Column	Disposal Medium	Depth (inches)
A	Sandstone	56
B	Shale	62
C	Alluvium	58
D	Interburden	58
E	Limestone	61
F	Glacial Till	63

TABLE D-4. LABORATORY CONTROL COLUMN ASSEMBLY PROCEDURE

1) Cut each pipe into one-foot, three-foot and 3.5-foot sections.

2) Seal one end of the one-foot section, drill a hole for sample tube access.

3) Fill the section with coarse sand, inserting porous cups bedded in 200 mesh sand at the base. Lead the tube out the holes and seal.

4) Join three-foot section, mount in rack, weigh and hand place media on top. Join 3.5-foot section, continue filling to a total depth of six feet of media.

5) Install drip tube for water application above top of media.

Records of daily rainfall depths at the field site were converted to equivalent volumes, and each column was irrigated with that volume of deionized water. The laboratory columns were operated in parallel with the field control cells, but delayed by 54 days. The porous ceramic cup at the base was kept under a constant 0.3 atmosphere vacuum to remove all leachate generated and to ensure unsaturated flow.

D.2.4.2 Column Leaching Study

Column leaching experiments performed in the laboratory using both waste and disposal media were similar to those in the field (except at reduced scale). They were designed as a point of reference between the batch equilibration tests and the field cells. The laboratory batch equilibration and field cell data have a gap spanning almost two orders of magnitude in volume-per-mass ratio. The purpose of the column leaching studies was to close this "data gap" to aid in correlation and understanding of the relation of field data to laboratory batch equilibration data. Column leaching is a good method of evaluating pollutant generation and mobility in a body of waste.

A scaled down study was formulated to provide better understanding of the leaching behavior of the field cells. This limited program consisted of five columns. The two principal objectives were: 1) to define the column leaching and attenuation/mobilization behavior of Exxon PFBC and Alliance AFBC wastes with the sandstone and shale media respectively; and 2) to determine the difference between the leaching behavior of ground and unground Exxon PFBC waste. Two columns per waste were required, the first to define the leaching behavior, and the second to determine the attenuation/mobilization interaction with a disposal medium. Because only one disposal medium could be investigated with each waste, the attenuation/mobilization of Alliance AFBC waste with sandstone and the attenuation/mobilization of Exxon PFBC waste with shale were selected.

D.2.4.2.1 Leaching Column Design

The columns were designed to contain materials in a configuration analogous to the field cells. These configurations are shown in Figure D-5. The columns were prepared using 3" ID plexiglass tubing. Porous discs were used at the ends of the columns. Sand, shale, and sandstone were loosely packed to the desired thickness. A detailed diagram of the columns is shown in Figure D-6.

As noted, the columns were designed to close the gap of chemical data in the field and lab studies. The column design allows definition of chemical behavior in the volume-to-mass-ranges from 0.34 to 2.76 mL/g, representing the pore volume displacements of approximately one to eight, assuming 42 percent porosity. Table D-5 shows the calculations made in designing the columns.

Leaching began with addition of sufficient deionized water to saturate the columns (250 to 750 mL). Liquid addition to the columns was based on proportional residence time of liquid contact with solids in the field cells. Assuming leachate appearance from an eight foot field cell three days after a rain (eight ft in 72 hrs), about 18 hours of contact were planned to duplicate leachate residence in a two foot lab column. Every two weeks, an additional 250 mL of deionized water was added and collected after approximately 18 hours. A gravity flow system was used unless plugged-flow occurred. If plugging occurred, pressure was applied with nitrogen gas to achieve the desired residence time. One aliquot was generated every two weeks to simulate average rainfall frequency.

After collection, each leachate was analyzed for the same chemical parameters as in the batch equilibration protocol. This procedure included splitting and preservation shown in Figure D-7.

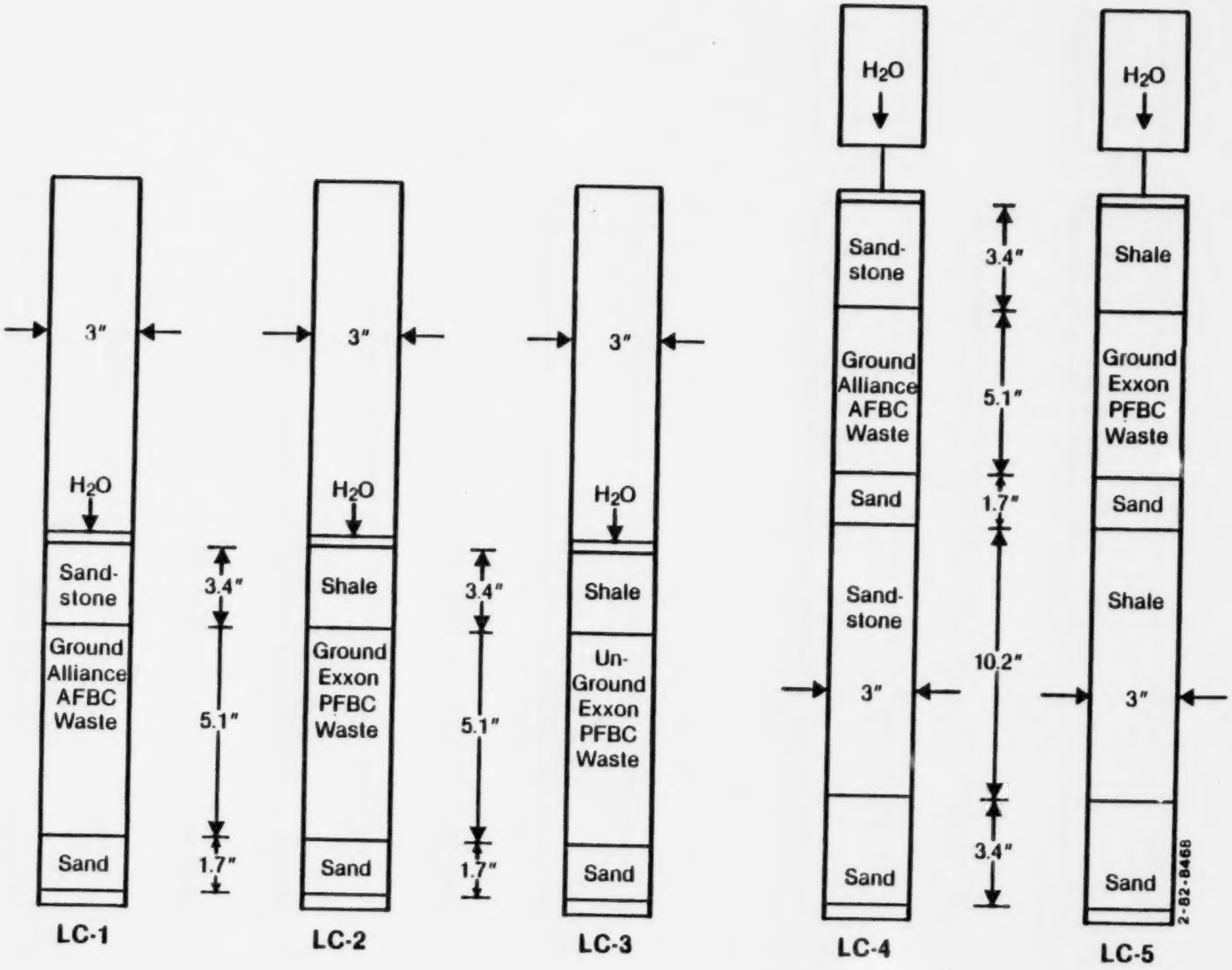
H2O
H2O
3"
3"
3"
3"
3"
H2O
H2O
H2O
Sand-stone
Ground Alliance AFBC Waste
Sand
LC-1
3.4"
5.1"
1.7"
Shale
Ground Exxon PFBC Waste
Sand
LC-2
3.4"
5.1"
1.7"
Shale
Un-Ground Exxon PFBC Waste
Sand
LC-3
Sand-stone
Ground Alliance AFBC Waste
Sand
Sand-stone
Sand
LC-4
3.4"
5.1"
1.7"
10.2"
3.4"
Shale
Ground Exxon PFBC Waste
Sand
Shale
Sand
LC-5
2-82-8468

Figure D-5. Schematic Configuration of the Laboratory Leaching Columns.

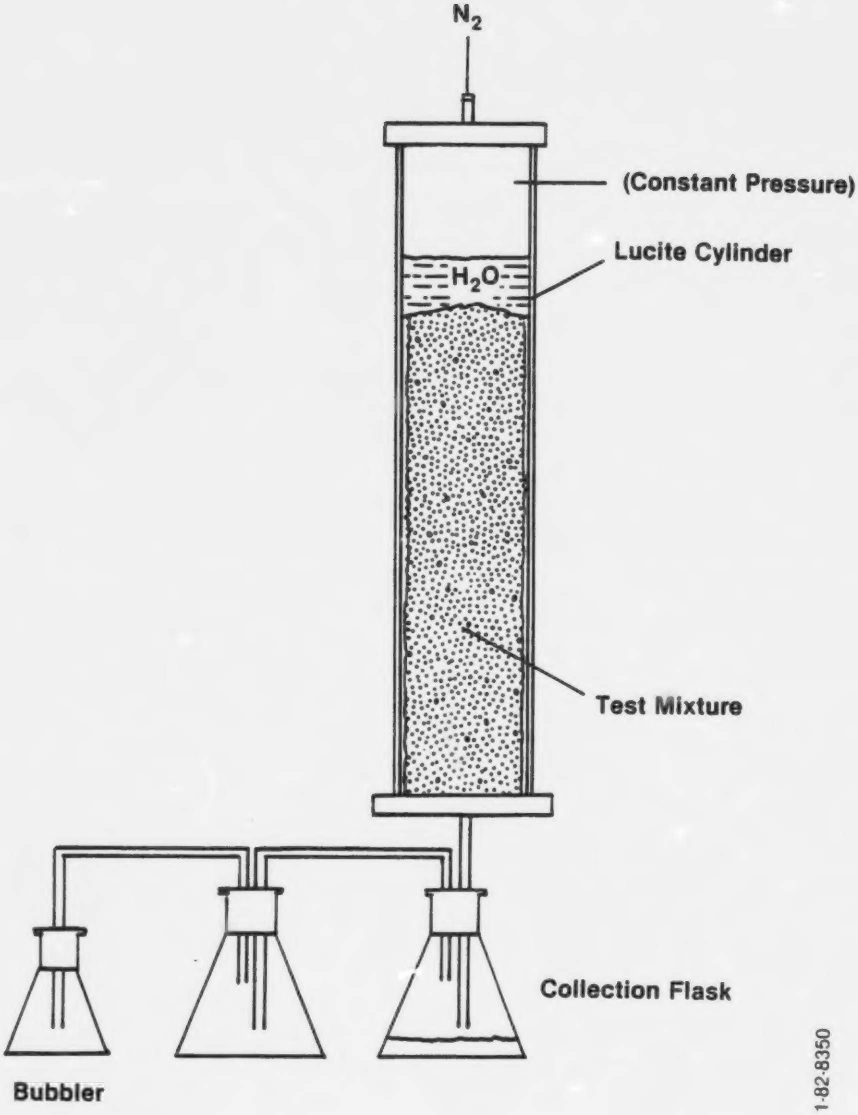
N_2
(Constant Pressure)
Lucite Cylinder
H_2O
Test Mixture
Collection Flask
Bubbler
1-82-8350

Figure D-6. Detailed Diagram of Laboratory Leaching Columns.

TABLE D-5. CALCULATION OF VOLUME-PER-MASS RATIOS, WASTE VOLUME, AND PORE VOLUME DISPLACEMENT FOR THE FBC COLUMN LEACHING STUDIES

Measured Parameters:

Column diameter: 3 inches
Height of waste in column: 5.1 inches - 12.9 cm
Weight of dry waste in column: 725 g
Specific gravity of waste: 2.94 (g/cc)
Apparent bulk density of waste: 1.23 g/cc
Minimum aliquot volume of leachate for analysis: 250 mL

1. Volume to mass ratio for column leachates:

The first aliquot will be analyzed after 250 mL are collected.
250 mL/725g waste = 0.34 mL/g.

The last aliquot will be analyzed after 2000 mL are collected.
2000 mL/725g waste = 2.76 mL/g.

2. Waste volume in column:

$V = h\pi r^2$
where, V is volume,
h is height of column, and
r is radius of column.

$V = (12.9\ \text{cm})(3.14)(14.5\ \text{cm}^2) = 588\ \text{cm}^3$

3. Pore volume displacements.

Porosity = percent void volume between specific gravity and apparent bulk density.

Percent Void Volume = 2.34 g/cc x 100% = 42%
= 2.94 g/cc

Volume of pores in waste = 42 percent of waste volume
One pore volume = $(0.42)(588\ \text{cm}^3) = 247\ \text{cm}^3$ or mL

Aliquots taken in this study represent 1 to 8 pore volume displacement.

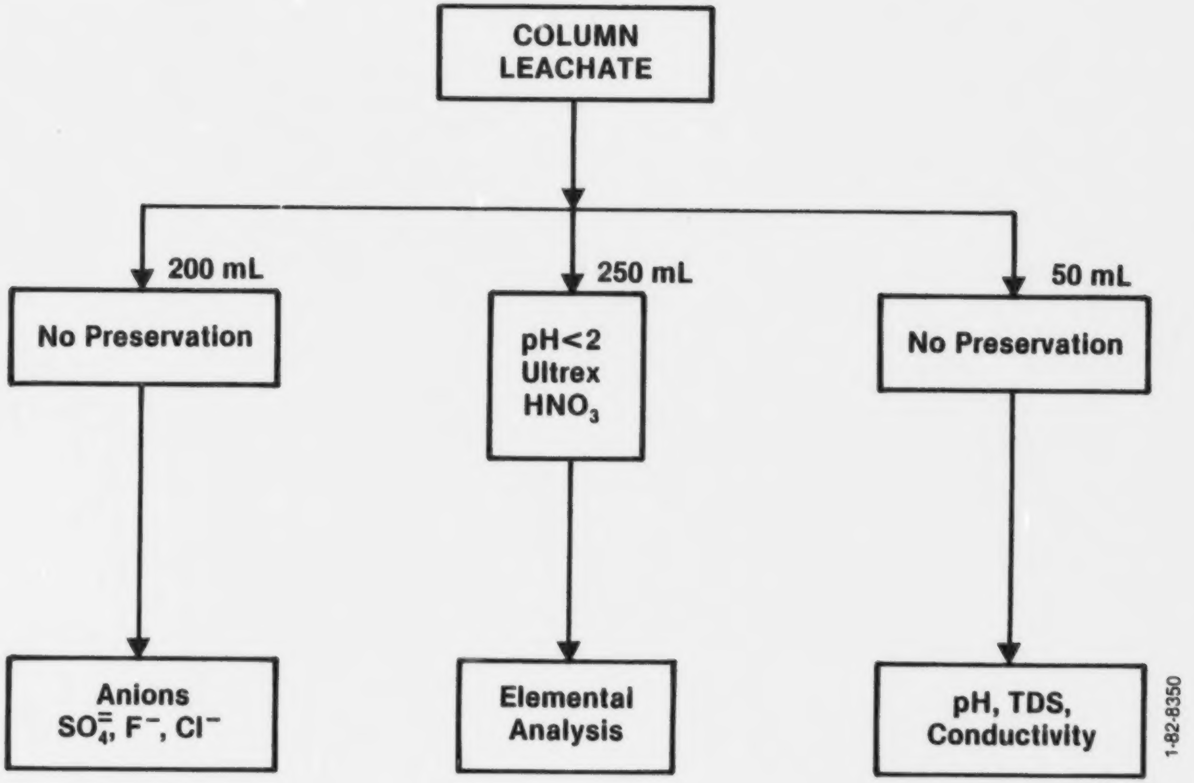
COLUMN LEACHATE
200 mL
250 mL
50 mL
No Preservation
pH<2 Ultrex HNO3
No Preservation
Anions SO4=, F−, Cl−
Elemental Analysis
pH, TDS, Conductivity
1-82-8350

Figure D-7. Preservation Procedures for Column Leachates.

D.2.4.2.2 Leaching Column Preparation and Operation

The wastes were first composited in the same ratios as for other components of the study (see Appendix A). After compositing, the wates were ground as required to meet the requirements for the columns and then hydrated slowly to prevent steam explosions. The Exxon PFBC waste was hydrated at a waste-to-water ratio of 8:1. This hydration was much less violent than it was for the AFBC waste. In both cases, 725 g of dry material were hydrated to correct ratios and packed loosely to a depth of 5.1 in.

D.2.5 Corollary Laboratory Studies

As noted previously, several corollary studies were performed to evaluate certain experimental procedures used in the laboratory investigations.

D.2.5.1 Sample "Representativeness" Determination

A sample "representativeness" investigation was performed to evaluate the cause of variability observed in the data for the Step 1 leachates from the first two wastes. The experiment was designed to determine if the observed variability could be due to inhomogeneity of the solids, nonduplication in the batch extractions, or variation in accuracy of the analyses from day to day. This study was performed as part of the quality control analysis for the program (see Appendix H).

The waste used for the representativeness study was the Alliance AFBC waste. A schematic illustration of the experiment is shown in Figure D-8. Approximately 10 kg of the waste (which remained after the initial batch leaching protocol was performed) were remixed, and five individual samples of about 250 g each were removed. The samples were labeled A through E. Each sample was throughly mixed and divided into four components. The first two components were used for physical properties determinations and solid

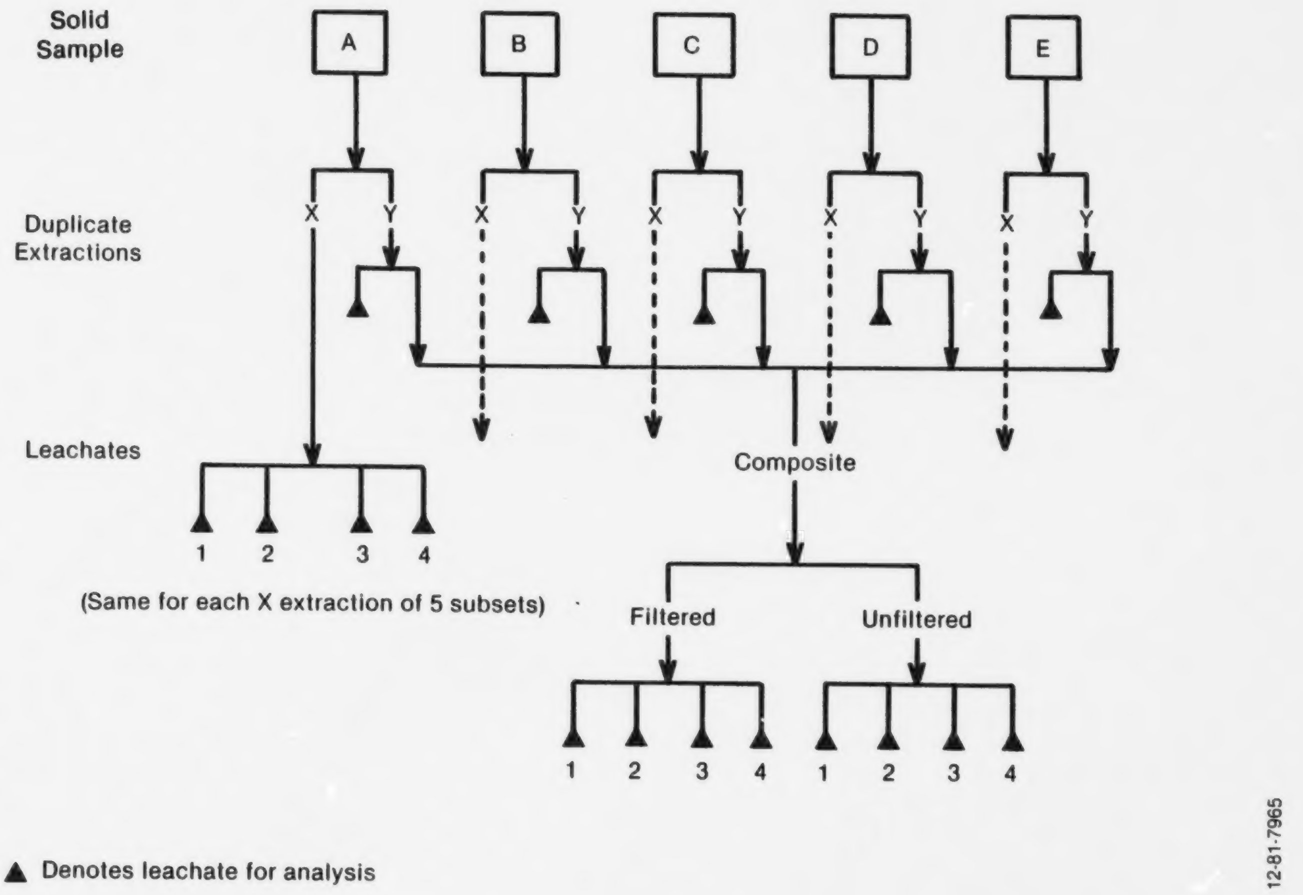
Solid Sample
A
B
C
D
E
Duplicate Extractions
X
Y
Leachates
1
2
3
4
(Same for each X extraction of 5 subsets)
Composite
Filtered
Unfiltered
1
2
3
4
1
2
3
4
▲ Denotes leachate for analysis
12-81-7965

Figure D-8. Flow Chart for the Solids "Representativeness" Experiment.

sample elemental analyses (see Appendices B and C). The two remaining components were used for Step 1, seven-day extractions. The duplicate extractions were labeled X and Y and were performed using a solid:liquid ratio of 50 g to 150 mL. At the end of the seven-day period, the X extractions were each divided into four portions which were individually analyzed at one-month intervals.

D.2.5.2 Evaluation of Filtration Effects

Samples from the laboratory protocol studies with the Exxon PFBC and Alliance AFBC wastes were processed with centrifugation rather than filtration. This procedure afforded considerable time advantages but left concern that the resulting analytical data may, in part, be related to the separation procedure employed. To evaluate this potential, a comparison between results obtained on filtered and unfiltered samples was built into the sample representativeness experiment (Figure D-8).

From each of the Y extractions a 150 mL portion was retained to analyze with the first of the X samples. The remaining 300 mL from each of the Y extractions was combined into one large composite sample. One-half of the composite was filtered and one-half was retained unfiltered. Each of the two portions was then subdivided into four aliquots. Each of the aliquots was analyzed at monthly intervals along with the X extractions.

D.2.5.3 Evaluation of the Effects of Sample Grinding

In the field cell studies, the wastes were used as received (after hydration), whereas in the laboratory batch leach studies the wastes were ground before they were used. Several considerations led to the decision to grind the samples used in lab studies, including uniformity of particle size (which could be more readily characterized) and better assurance of bulk sample homogeneity for replicate studies.

To evaluate the effect of this difference on the leaching characteristics of the FBC wastes, a comparison of ground with unground waste was made with two of the wastes. Early in the study, four replicate Step 1 extractions were conducted on unground samples of the Exxon PFBC waste. Then, with the Georgetown AFBC waste, a more extensive comparison was conducted which was carried through protocol Steps 1 and 2 (nine replications). The Georgetown wastes were run in duplicate.

D.2.6 Method of Sample Coding

D.2.6.1 General Coding Scheme

Because of the large number of samples that were generated in the laboratory protocol and related studies, a convenient, descriptive symbolism was developed to code the samples. Each sample was given a code of at least seven characters which indicates sample type (waste, leachate, or attenuation media), step in protocol, leaching time, number of repetitions of step, identification of waste, identification of attenuation medium, and sample duplication. This symbolism is employed to present the analytical data in Appendix J.

The order in which the symbolism fits together is A, b, c, d, e, f, g. These characters are defined as follows:

A The first character of the code is a letter identification of the sample type, as follows:

S Denotes a solid FBC waste residue.

A Denotes a solid disposal medium residue.

L Denotes a liquid phase (leachate) from a laboratory extraction step involving leaching and/or attenuation.

b Identifies the specific step in the protocol (b = 1 through 7),

c Denotes the time period for a particular extraction (c = 1, 2, or 7 for 1 day, 2 days, or 7 days of extraction, respectively),

d Denotes the number of times a secondary leaching or attenuation step has been repeated. (d = 0 through 9; 0 is used in the Steps 1 and 4 which were not repeated.)

e Is a number identifying the FBC waste residues, as follows:

e = 1 Exxon PFBC waste

e = 2 Huntington FGD waste

e = 3 Alliance AFBC waste

e = 4 Georgetown AFBC waste

f Is a number identifying the disposal media, as follows:

f = 08 Shale

f = 09 Mine interburden

f = 10 Sandstone

f = 11 Greer limestone

f = 12 Glacial till

f = 13 Alluvium

f = 14 Greenbrier Limestone

g Denotes multiple extractions. All extractions were performed in at least duplicate (A and B). If more than two extractions are performed, the additional samples generated are assigned additional letters (C, D, E, etc.) in the order of sample generation. Not all of the multiple extractions are performed at the same time (e.g., Step 1). For some leachate samples, the letters are preceded by an asterisk (*), which denotes that a leachate sample is a composite of several leachates. The absence of an asterisk indicates an individually generated leachate.

Some examples of the use of the symbolism to identify leachate and solid samples are as follows:

L470108C Denotes a leachate sample from Step 4 in the protocol which was generated during a seven-day extraction performed without repetition. The attenuation medium was shale and the extraction was done with Exxon PFBC leachate. This is the third extraction of multiple extractions.

L573314B	Denotes a leachate sample from Step 5 in the protocol which has come from the third repetition of the step. The equilibration time was seven days. Limestone disposal medium was equilibrated with Alliance AFBC leachate to produce this sample. This is the second of duplicate extractions.
A573314B	Denotes the solid disposal medium residue that correlates with the preceding leachate sample. The solid is always coded to match up with its liquid leachate phase.
L170300*C	Denotes a leachate sample from Step 1 in the protocol. The sample was split from a composite carried forward to Step 3, 4, or 5. The individual leachates comprising the composite were seven day leachates generated by contacting AFBC waste with deionized water. No repetition of the step was performed.

D.2.6.2 Special Studies Coding

Disposal Media Extractions

The individual soils used in the attenuation/mobilization studies were subjected to Step 1 extractions with deionized water. These samples were coded similar to Step 1 extractions for the waste samples except that a zero is entered for the waste identity followed by the soil code number. For example:

L170008A

would be a Step 1 leachate of the shale (08) medium. The letter A indicates the first of the replicates. Since an earlier study was done on three of the soils (08, 09 and 10) plus the original limestone (Greer limestone, code number 11) a double alphabetical character is used to differentiate from the later and more extensive study. For example, L170008AA would be a Step 1 extraction of shale but conducted at a different time than the L170008A sample.

Sample "Representativeness" Coding

A total of 33 leachate and five solid samples were generated during the representativeness experiment. The leachates were coded using the following symbolism:

L1703 A X - 1

The first four characters are standard for the experiment and denote a Step 1 leachate that is non-repetitive using Waste 3 (Alliance AFBC). The fifth character denotes the solid from the representativeness experiment (Samples A to E). The sixth character denotes the X or Y duplicate extraction and the last character denotes the order of the monthly analysis. For the composited sample, Y, the fifth and sixth characters are both 0, and U or F was used to denote filtered or unfiltered with an asterisk (*) to denote that the sample was from a composite.

Ground Versus Unground Samples

For the Georgetown AFBC waste, those samples coded by a final A or B represent the normal ground waste samples. A final C or D designation applies to unground waste.

Waste Extraction with Media Step 1 Leachate

This experiment generated a total of 32 leachates and four solid samples for analysis. The initial and secondary leachates were coded using a symbolism to indicate that the steps were modifications to the usual protocol. For example, the initial leaching and the third repetition of the secondary leaching using sandstone are coded as M170310 and M273310, respectively.

RCRA Extraction Procedure Samples

The RCRA/EP leachate samples are designated by the first four characters, RCRA followed by the waste designation, 01, 03, or 04 and then A or B to differentiate between the duplicate samples. For example, RCRA 01 B indicates the second of duplicate extractions of Waste 1 (Exxon PFBC) by the RCRA procedure.

D.2.6.3 Laboratory Column Studies

D.2.6.3.1 Disposal Media Control Columns

The laboratory control columns for leaching of the six disposal media were coded with two characters followed by the sampling date. In all cases, the second character is R which designates the sample as having originated from a laboratory control column containing disposal media only. The first character identifies the medium contained in the column according to the following:

A = Sandstone
B = Shale
C = Alluvium
D = Interburden
E = Limestone
F = Glacial Till

For example, DR 100780 indicates a sample from an interburden (medium only) laboratory column leachate taken on 7 October 1980.

D.2.6.3.2 Laboratory Leaching Columns

The leaching columns were numbered LC-1 through LC-5 as indicated previously in Figure D-5. Leaching column samples are identified by an LC prefix, which indicates Lab Column, followed by the column number and the date of sample removal. For example, LC5070781 indicates a sample taken from column LC-5 on 7 July 1981.

D.2.6.4 Specific Step 1 Leachates Used for Attenuation/Mobilization Studies

D.2.6.4.1 Exxon PFBC Waste

Composites of several Step 1 leachates were used for Step 4 and 5 of the protocol. These composites were not analyzed specifically but presumed to be adequately represented by the average of analytical results from previous Step 1 extracts. Therefore, all fractional attenuation values for Exxon PFBC waste leachates (described below) have been computed relative to the same initial concentration value.

D.2.6.4.2 Alliance AFBC Waste

In Table D-1 (above), it can be seen that a large number of Step 1 replicate values were obtained (36) for the Alliance AFBC waste. Many of these samples were Step 1 composites used in the disposal media attenuation/mobilization studies of Steps 4, 5, and 6. Table D-6 provides the specific match-up of individual Step 1 samples with an attenuation/mobilization step. Thus, the fractional attenuation values calculated for this waste come directly from a leachate that has been independently analyzed.

D.2.6.4.3 Georgetown AFBC Waste

As was the case for the Alliance AFBC waste, Step 1 leachates of known composition were used for the attenuation/mobilization evaluation. Only Step 4 of the protocol was performed, so only two composite solutions were required. The *A composite was used for all Step 4, replicate A samples, and the *B composite was used for all replicate B samples.

D.2.7 Chemical Analyses Performed

The chemical analyses performed on the FBC batch leachates are summarized in Table D-7. In this table, the parameters determined for each

TABLE D-6. ALLIANCE AFBC LEACHATES ANALYZED TO CHARACTERIZE COMPOSITES PLACED IN CONTACT WITH DISPOSAL MEDIA (Steps 4, 5, 6)

Step	Shale xx=08	Interburden xx=09	Sandstone xx=10	Glacial Till xx=12	Alluvium xx=13	Limestone xx=14
L4103xxA	L170300*BB	L170300*BB	L170300BB	L170300*BB	L170300*BB	L170300*BB
B	*CC	*CC	*CC	*CC	*CC	*CC
L4203xxA	L170300*BB	L170300*BB	L170300*BB	L170300*BB	L170300*BB	L170300*BB
B	*CC	*CC	*CC	*CC	*CC	*CC
L4703xxA	L170300*A	L170300*A	L170300*A	L170300*A	L170300*A	L170300*A
B	*B	*B	*B	*B	*B	*B
L4703xxC	L170300*H	L170300*N	L170300*T	L170300*V	L170300*X	L170300*Z
D	*I	*O	*U	*W	*Y	*AA
L5713xxA	L170300*C	L170300*C	L170300*C	L170300*C	L170300*C	L170300*C
B	*D	*D	*D	*D	*D	*D
L5723xxA	L170300*E	L170300*E	L170300*E	L170300*E	L170300*E	L170300*E
B	*F	*F	*F	*F	*F	*F
L5733xxA	L170300*H	L170300*H	L170300*H	L170300*H	L170300*H	L170300*H
B	*I	*I	*I	*I	*I	*I
L5743xxA	L170300*J	L170300*J	L170300*J	L170300*J	L170300*J	L170300*J
B	*K	*K	*K	*K	*K	*K
L5753xxA	L170300*L	L170300*L	L170300*L	L170300*L	L170300*L	L170300*L
B	*M	*M	*M	*M	*M	*M
L5763xxA	L170300*N	L170300*N	L170300*N	L170300*N	L170300*N	L170300*N
B	*O	*O	*O	*O	*O	*O
L5773xxA	L170300*P	L710300*P	L170300*P	L170300*P	L170300*P	L170300*P
B	*Q	*Q	*Q	*Q	*Q	*Q
L5783xxA	L170300*R	L170300*R	L170300*R	L170300*R	L170300*R	L170300*R
B	*S	*S	*S	*S	*S	*S
L5793xxA	L170300*T	L170300*T	L170300*T	L170300*T	L170300*T	L170300*T
B	*U	*U	*U	*U	*U	*U
L6713xxA	L470308C	L470309C	L470310C	L470312C	L470313C	L470314C
B	D	D	D	D	D	D
L6723xxA	L671308A	L671309A	L671310A	L671312A	L671313A	L671314A
B	B	B	B	B	B	B
L6733xxA	L672308A	L672309A	L672310A	L672312A	L672313A	L672314A
B	B	B	B	B	B	B
L6743xxA	L673308A	L673309A	L673310A	L673312A	L673313A	L673314A
B	B	B	B	B	B	B
L6753xxA	L674308A	L674309A	L674310A	L674312A	L674313A	L674314A
B	B	B	B	B	B	B

*Composite samples

TABLE D-7. METHODS OF CHEMICAL ANALYSIS OF LEACHATES FROM BATCH EQUILIBRATION STUDIES

Element/ Species	Exxon PFBC Waste	Alliance AFBC Waste	Georgetown AFBC Waste	Huntington FGD Waste	Auxiliary Studies[1]
Elemental Analysis					
Al	ICAPES[2]	ICAPES	ICAPES	ICAPES	ICAPES
As	ETAAS[3]/ICAPES[a]	–	–	–	–
B	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Ba	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Be	ETAAS/ICAPES[a]	ICAPES	ICAPES	–	–
Ca	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Cd	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Co	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Cr	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Cu	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Fe	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Hg	CVAAS[5,c]	–	–	–	–
K	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Li	FAAS[4]/ICAPES[b]	ICAPES	ICAPES	–	–
Mg	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Mn	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Mo	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Na	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Ni	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Pb	ETAAS/ICAPES[a]	–	–	–	–
Se	ETAAS/ICAPES[b]	–	–	–	–
Si	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Sr	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Ti	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
U	ICAPES[d]	–	–	–	–
V	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Zn	ICAPES	ICAPES	ICAPES	ICAPES	ICAPES
Water Quality Analyses					
Cl	IC[6,e]	IC[e]	IC	IC	–
F	Potentiometry	Potentiometry	Potentiometry	Potentiometry	Potentiometry
pH	Potentiometry	Potentiometry	Potentiometry	Potentiometry	Potentiometry
SO_4	IC	IC	IC	IC	IC
Sp. Cond.	Conductivity	Conductivity	Conductivity	Conductivity	Conductivity
TDS	Gravimetry	Gravimetry	Gravimetry	Gravimetry	Gravimetry
TIC	–	–	Instr. TIC	–	Instr. TIC
TOC	Instr. TOC[7,e]	Instr. TOC[e]	Instr. TOC[e]	–	Instr. TOC[e]

[1] Auxiliary studies include nonroutine protocol analyses and analyses for corollary laboratory studies.
[2] ICAPES – Inductively Coupled Argon Plasma Emission Spectroscopy.
[3] ETAAS – Electrothermal Atomic Absorption Spectroscopy (graphite furnace).
[4] FAAS – Flame Atomic Absorption Spectrosocpy.
[5] CVAAS – Cold Vapor Atomic Absorption Spectroscopy.
[6] IC – Ion Chromatography.
[7] Instr. TOC – Instrumentally determined Total Organic Carbon.
a – Atomic Absorption Spectroscopy, Protocol Step 1; Restricted ICAPES analysis.
b – Atomic Absorption Spectroscopy, Protocol Steps 1, 4-6; Restricted ICAPES analysis.
c – Atomic Absorption Spectroscopy, Protocol Step 1.
d – Restricted ICAPES analysis.
e – Analysis restricted to several samples only.

study are presented as well as the analytical techniques employed. The methods of analysis are described more fully in Appendix A.

The parameters listed in Table D-7 are divided into two broad categories, elemental analyses and water quality analyses. The primary analytical technique used for elemental analysis was inductively coupled argon plasma emission spectroscopy (ICAPES). Atomic absorption spectroscopy (AAS) was used early in the program to complement the ICAPES analyses. Seven water quality parameters were determined using six analytical techniques:

- pH by potentiometry (glass electrode);
- Fluoride by potentiometry (ion selective electrode);
- Specific conductance;
- Total dissolved solids by gravimetry;
- Sulfate and chloride by ion chromatography; and
- Total organic carbon by the instrumental method.

Data were obtained for the laboratory column studies using the same analytical procedures as were used for the batch equilibration studies.

D.3 Leachate Generation from FBC Wastes

The waste leaching data for each of the wastes and the individual steps of the protocol were examined to allow comparison of the wastes, to provide a means of assessing the magnitude of potential leachate problems, and to compare the lab behavior of the wastes and disposal media with their behavior in field cells. The raw data for the leaching behavior are given in Appendix J. In the following paragraphs, the results of Step 1 seven-day leaching are discussed first. Subsequent leaching steps (2 and 3) are then presented. A comparison of one-, two-, and seven-day leaching results is also made.

D.3.1 Step 1 Leachate Behavior (Seven-Day)

Tables D-8 to D-11 contain summary statistics for the three FBC wastes and one FGD sludge waste. Since all wastes were extracted under the same experimental conditions (except that the Georgetown AFBC samples were filtered before analysis), direct comparisons of the leachate compositions can be made.

Step 1 leachate from each of the wastes were similar in that they all had high calcium and sulfate concentrations was well as high pH. A comparison of the three FBC waste leachates with the FGD sludge leachate can be made by examining the mean concentration values. The FGD sludge leachate contained higher concentrations of B, Co, Cr, F, K, and Si. Among the three FBC wastes leachates, the Exxon PFBC leachate had higher boron and molybdenum concentrations, whereas the two AFBC waste leachates had higher chloride and strontium concentrations. The Georgetown AFBC waste leachate showed a slightly higher total organic carbon concentration--roughly a factor of three based on median concentrations. Otherwise, the FBC leachates appeared to be generally low in trace/heavy metal concentrations and not appreciably different from FGD sludge leachates.

Certainly, the high pH played a role in the observed trace/heavy metal behavior. While many heavy metals are amphoteric and would be expected to become more soluble at high pH, other controls on their solubility can be operative in such a complex system. Adsorption on and coprecipitation with other metal hydroxides can occur. Slightly soluble metal carbonates can regulate solution concentration of some metals such as Zn, Ni, Pb, and Cd. Magnesium concentration would be controlled directly by simple hydroxide solubility (one of the few metals to behave so). Uniformly, the magnesium concentrations were low.

Table D-12 presents a tally of the percent of the original bulk solids content of the elements or species which was extracted in Step 1. To provide tracking of this process through Step 2 below, only the A and B replicates have been used in the computation of percent leached. In some

TABLE D-8. SUMMARY STATISTICS FOR EXXON PFBC STEP 1 (SEVEN-DAY) LEACHATE CONCENTRATIONS[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	12	0	0.8	0.8	0.29	1.5	0.34
As	8	8	0.04	0.04	0.04	0.04	0
B	12	0	11	11	4.9	15	4.3
Ba	12	0	0.2	0.18	0.12	0.3	0.06
Ca	8	0	1670	1660	1340	1900	180
Cd	12	12	0	0	0	0	0
Cl	8	0	4.5	2.6	2	9.3	2.9
Co	12	8	0.59	0.07	0.07	2.2	0.79
Cr	12	2	0.09	0.1	0	0.2	0.06
Cu	12	8	0.02	0	0	0.09	0.03
F	12	0	0.96	0.83	0.67	1.9	0.35
Fe	12	0	0.19	0.17	0.07	0.39	0.09
K	12	8	251	20	20	870	350
Mg	12	0	1.4	0.68	0.16	6.3	1.8
Mn	12	7	0	0	0	0.01	0.01
Mo	4	0	2.5	2.4	2.2	2.9	0.33
Na	12	1	17	17	2.5	34	9.3
Ni	12	7	0.08	0.01	0.01	0.26	0.1
Pb	8	8	0.03	0.03	0.03	0.03	0
pH[2]	12	0	12.0	11.9	11.5	12.5	0.4
Se	8	8	0.06	0.06	0.06	0.06	0
Si	12	0	1.3	0.78	0.39	2.8	0.87
SO_4	12	0	1200	1210	1080	1260	58
Sp. Cond.[3]	12	0	8130	9500	2100	9800	2800
Sr	12	0	2.8	2.8	1.1	4.2	0.95
TDS	8	0	3210	3310	2220	4220	890
Ti	12	8	0.05	0	0	0.16	0.07
TOC	3	0	1.3	1.3	1.1	1.4	0.15
V	12	8	0.09	0	0	0.33	0.13
Zn	11	0	0.13	0.11	0.01	0.3	0.1

[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] Units are in micromhos/cm.

TABLE D-9. SUMMARY STATISTICS FOR ALLIANCE AFBC STEP 1 (SEVEN-DAY) LEACHATE CONCENTRATIONS[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	36	1	1	1	0.02	2.6	0.66
B	36	0	3.5	3.3	0.72	8	2.3
Ba	36	1	0.13	0.11	0	0.25	0.07
Be	28	0	0	0	0	0.01	0.003
Ca	32	0	1340	1200	900	2770	410
Cd	36	1	0.04	0.04	0	0.1	0.026
Cl	36	0	51	51	43	62	4.1
Co	36	0	0.08	0.07	0.01	0.18	0.049
Cr	36	0	0.12	0.12	0.04	0.26	0.066
Cu	36	0	0.14	0.13	0.02	0.37	0.1
F	36	0	0.25	0.25	0.1	0.44	0.079
Fe	36	0	0.08	0.08	0.01	0.18	0.043
K	36	0	44	43	32	55	5.8
Li	28	0	0.36	0.37	0.25	0.46	0.068
Mg	36	8	0.81	0.66	0.02	2.7	0.86
Mn	36	0	0.02	0.02	0.01	0.04	0.01
Mo	36	0	0.42	0.43	0.35	0.49	0.034
Na	36	0	13	13	10	17	1.6
Ni	36	0	0.11	0.1	0.04	0.22	0.052
pH[2]	36	0	12.4	12.4	12.3	12.5	0.094
Si	36	0	0.55	0.54	0.33	0.96	0.16
SO_4	36	0	1110	1100	1010	1190	57
Sp. Cond.[3]	36	0	8100	8200	3250	8700	858
Sr	32	0	21	20	14	41	6.01
TDS	36	0	3780	3830	3500	4030	137
Ti	36	0	0.32	0.3	0.07	0.83	0.22
TOC	2	0	1.2	1.2	0.5	1.9	0.99
V	36	0	0.26	0.24	0.06	0.62	0.16
Zn	36	0	0.04	0.04	0.01	0.07	0.02

[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] Units are in micromhos/cm.

TABLE D-10. SUMMARY STATISTICS FOR GEORGETOWN AFBC STEP 1 (SEVEN-DAY) LEACHATE CONCENTRATIONS[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	6	5	0.17	0.13	0.13	0.42	0.12
B	6	3	0.16	0.05	0.02	0.44	0.2
Ba	6	0	0.19	0.19	0.19	0.2	0.005
Be	6	4	0	0	0	0	0.001
Ca	6	0	1500	1500	1400	1600	89
Cd	6	6	0.02	0.02	0.02	0.02	0.001
Cl	6	0	24	24	23	25	0.82
Co	6	6	0.01	0.01	0.01	0.01	0
Cr	6	2	0.05	0.05	0	0.1	0.046
Cu	6	4	0.03	0	0	0.08	0.04
F	6	0	0.16	0.15	0.11	0.25	0.052
Fe	6	6	0.02	0.02	0.02	0.02	0
K	6	0	18	18	16	20	1.6
Li	6	0	0.5	0.49	0.4	0.61	0.088
Mg	6	0	2.7	2.8	1.7	3.2	0.57
Mn	6	2	0.01	0.01	0	0.02	0.008
Mo	6	4	0.02	0	0	0.06	0.025
Na	6	0	6.5	6.5	4.9	8.2	1.1
Ni	6	2	0.04	0.05	0.01	0.07	0.029
pH[2]	6	0	12.5	12.5	12.5	12.6	0.04
Si	6	0	2.4	2.5	1.1	4	1.1
SO_4	6	0	1400	1390	1210	1530	120
Sp. Cond.[3]	6	0	7780	7700	7500	8300	310
Sr	6	0	13	13	13	14	0.41
TDS	6	0	4000	4050	3740	4100	140
Ti	6	4	0.06	0.01	0.01	0.18	0.079
TIC	6	2	4.3	5.7	1	6.3	2.6
TOC	6	0	3.9	3.6	3.5	4.6	0.5
V	6	4	0.02	0.01	0.01	0.03	0.012
Zn	6	6	0.01	0.01	0.01	0.01	0

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are in micromhos/cm.

TABLE D-11. SUMMARY STATISTICS FOR HUNTINGTON FGD STEP 1 (SEVEN-DAY) LEACHATE CONCENTRATIONS[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	12	0	3.4	3.1	1.1	6.5	1.8
B	12	0	28	27	25	30	1.4
Ba	12	0	0.43	0.35	0.3	0.81	0.17
Ca	12	0	1480	1490	1370	1570	65
Cd	12	12	0	0	0	0	0
Cl	12	0	0	0	0	0	0
Co	12	0	2.3	2.2	1.8	2.9	0.35
Cr	12	0	1.2	1.3	1	1.4	0.13
Cu	12	0	0.13	0.13	0.1	0.18	0.023
F	12	0	3.1	3.1	2.1	3.9	0.51
Fe	12	0	0.35	0.32	0.11	0.71	0.2
K	12	0	840	830	690	1000	92
Mg	12	0	0.24	0.23	0.1	0.4	0.095
Mn	12	0	0.02	0.02	0.02	0.03	0.002
Mo	12	0	2.1	2.1	1.7	2.6	0.27
Na	12	0	27	27	23	30	1.8
Ni	12	0	0.31	0.3	0.26	0.36	0.028
pH[2]	12	0	12.2	12.2	12.0	12.4	0.099
Si	12	0	6.2	6.5	3.1	11	2.3
SO_4	12	0	1180	1180	1150	1210	17
Sp. Cond.[3]	12	0	7280	7500	5650	8300	770
Sr	12	0	8.8	8.9	8	9.5	0.46
TDS	12	0	3540	3540	3140	4010	290
Ti	12	0	0.27	0.29	0.14	0.45	0.094
V	12	0	0.39	0.38	0.31	0.48	0.049
Zn	12	0	0.03	0.03	0.02	0.03	0.004

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are in micromhos/cm.

instances, the solid waste content was too low for quantification for certain species, so no value was computed for percent extraction. When solution concentrations were below detection limits, the detection limit value was used in the computation and the percent extracted was reported as less than the resultant value.

TABLE D-12. PERCENT OF TOTAL SOLIDS CONTENT LEACHED FROM THE FBC WASTES IN STEP 1 OF THE LABORATORY PROTOCOL

Element/ Species	Percent of Total Leached					
	Exxon PFBC		Alliance AFBC		Georgetown AFBC	
	A	B	A	B	A	B
Al	0.019	0.015	0.019	0.025	<0.01	<0.01
B	21	20	3.2	5	<0.11	0.21
Ba	1.3	1.8	0.85	0.82	1.3	1.2
Be	–	–	0.21	0.42	–	–
Ca	6.1	7.5	4.4	4.7	5	5
Cd	<11	<11	55	90	–	–
Cl	26	8.9	62	64	62	65
Co	–	–	2	3.3	<3	<3
Cr	1.6	0.42	1.4	1.9	0.36	0.92
Cu	<0.04	<0.04	0.62	1.2	<0.2	<0.2
F	4.6	4.1	2	2.2	0.38	0.52
Fe	0.006	0.005	0.0004	0.0006	<0.001	<0.001
K	<2	<2	7.6	7.7	3.6	3.6
Li	–	–	–	–	12	13
Mg	0.014	0.006	0.067	0.16	0.67	0.63
Mn	<0.008	<0.008	0.012	0.015	0.021	0.055
Mo	–	–	12	15	<1.4	<1.4
Na	5.4	5.2	–	–	4.1	3.5
Ni	<0.4	0.4	1.1	1.5	<0.94	3.9
Si	0.015	0.011	0.008	0.009	0.041	0.045
SO_4	5.4	5.5	8.4	8.5	16	18
Sr	6.7	14	25	27	54	50
Ti	<0.001	<0.001	0.047	0.079	<0.014	<0.014
V	<0.07	<0.07	3.6	7	<0.3	<0.3
Zn	0.39	0.35	0.22	0.31	<0.44	<0.44

Two species showed high percent extractions from each of the wastes—chloride and strontium. Other species (Ca, SO_4, K, and Na) showed similar behavior for each waste and were leached in the range of 5 to 17 percent in the first (Step 1) extraction. Species with irregular behavior among the wastes but with high percent extraction for one or more wastes were boron, fluoride and vanadium. The balance of the chemical species have less than two percent of the solids content extracted. In many cases, the solid content was already low and the subsequent leachate content was also low. Iron and aluminum, which constituted significant proportions of the solid materials, were not strongly leached in spite of enhanced solubility of the simple forms at high pH.

Sulfate likely controlled the extent to which barium was leached from the waste and may have ultimately regulated the calcium leaching. However, calcium carbonate is much less soluble than calcium sulfate, and it is quite likely that calcium carbonate was precipitated in the leachate container. Carbonate or inorganic carbon measurements were not taken for the Exxon PFBC and Alliance AFBC leaching studies, but total inorganic carbon measurements were obtained on the Georgetown AFBC leachates. The median value (Table D-10) of 5.7 mg/L (range 1.0 to 6.3) as carbon translates to only 29.5 mg/L (4.75×10^{-4} molar) as carbonate. A computer modeling study of the calcium carbonate system on the leachates is described in Appendix I.

D.3.2 Behavior Upon Successive Leaching Steps

D.3.2.1 Protocol Steps 1 and 2

As noted, the volume-per-mass (VPM) ratio for protocol Step 1 was 10. Successive repetitions of Step 2 resulted in increasing VPM ratio, whereas Step 3 repetitions resulted in decreasing VPM ratio.

D.3.2.1.1 Concentration Trends

The behavior of individual species with continued extraction (Step 1 followed by Step 2 repetitions with resulting increasing VPM ratio) is summarized qualitatively in Table D-13. These summaries were generated by examination of plots like those given in Figures D-9 to D-35 (see Attachment 1) for each species and for each of the FBC wastes. Many species were not leached significantly from the waste solids, and some were essentially removed in the early extraction steps. For these species, a definable long-term trend is not indicated and variability is probably related to proximity

TABLE D-13. CONCENTRATION TRENDS FROM SUCCESSIVE LEACHING (Steps 1 and 2) OF FBC WASTES

Element/ Species	Trend in Leachate Concentration		
	Exxon PFBC	Alliance AFBC	Georgetown AFBC
Al	Increase	Increase	–
B	Decrease	Increase[2]	–
Ba	Slight Decrease	Slight Decrease	Increase then Decrease
Be	–	Increase	–
Ca	Decrease	Decrease[1]	Decrease
Cd	–	Increase	–
Cl	[1]	Constant	Decrease
Co	–	Increase	–
Cr	Decrease[1]	Increase	Decrease[1]
Cu	–	Increase	–
F	Constant	Decrease	Constant
Fe	Slight Decrease	Increase	–
K	–	Decrease	Constant
Li	–	Slight Decrease	Decrease
Mg	Decrease	Decrease then Increase	–
Mn	–	Increase	–
Mo	–	Decrease	–
Na	[1]	Decrease	Decrease[1]
Ni	No Change	Increase	[1]
Pb	–	–	–
pH	Slight Decrease	Constant	Slight Decrease
Se	–	–	–
Si	Increase	Increase[1]	Decrease
SO_4	Constant	Slight Decrease	Decrease
Sp.Cond.	Decrease	Constant	Decrease
Sr	Decrease	Decrease	Decrease
TDS	Slight Decrease	Slight Decrease	Decrease
Ti	–	Increase	–
TIC	–	–	Decrease
TOC	–	–	Constant[1]
V	–	Increase	–
Zn	Decrease	Increase	–

[1] Data scattered; trend not straightforward.

[2] Special problems.

of reported concentration values to analytic detection limits (see Appendix H). It is also possible that complex behavior, including time dependent and contact volume dependent changes in the solids surface character, led to oscillations in the leachate composition for specific species with successive extractions. When such variable behavior was encountered, the possibility of meaningful modeling was reduced. For this reason, the mathematical modeling efforts (Appendix G) were on occasion restricted to regions of volume per mass where definable trends were in evidence (typically VPM $\lesssim 30$). However, in some cases a clear trend continued throughout the extraction process. Descriptions and classifications of observed concentration trends and suggested chemical mechanisms to explain the trends are given in Appendix I.

Examination of Table D-13 shows that a consistent pattern among all three wastes for the Step 1-Step 2 extraction sequence is exhibited for very few elements or species. In all cases, calcium, strontium and total dissolved solids showed a continuing decline in concentration. Sulfate, pH and specific conductance declined slightly or remained constant. Similar behavior would be expected for very soluble species such as lithium, potassium and sodium, and where reliable data are available, the expected declines were observed.

Specific conductance should track TDS, and both in turn should be dominated by the calcium, sulfate and pH (via OH^-). Table D-13 shows these trends to be the case. Concentrations of all other species were so much smaller than for calcium, sulfate, and hydroxide that neither TDS nor conductance should be expected to be reliable predictors of any chemical species except calcium and sulfate.

A consistent pattern of variation with the Step 1 and Step 2 extraction sequence for other than those elements/species mentioned above is not evident. Silicates increased in concentration with continued extraction for the Exxon PFBC and Alliance AFBC wastes but decreased for the Georgetown AFBC waste. Chromium decreased for two wastes but increased for the third.

Barium decreased slightly for two wastes but increased initially for the third waste before decreasing.

Boron appeared to follow a classic desorption pattern for the Exxon PFBC waste with substantial concentrations occurring in the early extracts. Contrary to the behavior observed for Exxon PFBC wastes, boron extraction from the Alliance AFBC waste increased with successive extractions and had lower overall concentrations. Yet another pattern was found for the Georgetown AFBC waste, where much lower concentrations were obtained and no apparent trend could be determined.

D.3.2.1.2 Cumulative Percent Extracted

Whereas the concentration data appeared to be erratic and reflect different concentration behaviors for different species, cumulative mass extracted (when normalized to the original solids content, which is reported in Appendix C) offers another comparison method that "damps out" the data variability. Tables D-14, D-15 and D-16 present the cumulative percent of initial solids content extracted for selected species as a function of the Step 2 replications for the Exxon PFBC, Alliance AFBC and Georgetown AFBC wastes, respectively. Since the Exxon PFBC waste was only carried through seven Step 2 applications, comparison of all three wastes is made at Step 2, repetition seven.

Table D-17 lists those elements for which cumulative extraction data could be computed for all three wastes. High cumulative percent extractions were seen for Ca, SO_4, Cl, and Sr for each waste, although some differences among the wastes are clear. For example, the Alliance waste had much more extractable sulfate than the other two wastes. However, all extractable sulfate had been removed from the Georgetown waste by the third extraction. Magnesium was only slightly removed in all cases, which is expected at such high pH. Similarly, only a very small fraction of silicon was mobilized. Barium behavior was similar for the Exxon PFBC and Alliance AFBC wastes with a modest percent mobilization but was much more readily removed from the Georgetown AFBC waste. Fluoride mobilization also varied nearly by a factor

TABLE D-14. CUMULATIVE PERCENT OF TOTAL SOLIDS CONTENT LEACHED ON SUCCESSIVE REPETITIONS OF PROTOCOL STEP 2 FOR EXXON PFBC WASTE

Element/		Step 2 Repetition						
Species	Replicate	1	2	3	4	5	6	7
Al	A	0.033	0.052	0.052	0.081	0.12	0.18	0.27
	B	0.056	0.076	0.11	0.16	0.222	0.26	0.36
B	A	34	58	58	62	65	67	70
	B	30	55	63	67	70	72	74
Ba	A	2.9	4.2	4.2	5.0	5.6	6.1	6.6
	B	2.9	4.3	5.2	6.1	6.6	7.2	7.8
Ca	A	13	20	20	23	26	28	31
	B	12	20	24	27	29	32	34
Cl	A	30	37	37	37	37	46	46
	B	14	21	21	21	21	29	29
Cr	A	1.8	2.4	2.4	2.4	2.4	2.4	2.4
	B	2.2	2.5	2.6	2.5	2.5	2.5	2.5
F	A	6.6	9.6	12	15	16	19	20
	B	5.2	5.2	7.6	10	12	14	17
Fe	A	0.01	0.016	0.016	0.017	0.019	0.021	0.025
	B	0.019	0.026	0.03	0.032	0.036	0.037	0.041
Mg	A	0.019	0.022	0.022	0.023	0.026	0.028	0.031
	B	0.053	0.062	0.07	0.071	0.074	0.075	0.077
Na	A	12	21	21	20	21	21	21
	B	12	22	27	27	27	27	27
Ni	A	–	–	–	–	–	–	–
	B	–	–	1.1	1.1	3.2	3.2	3.2
Si	A	0.025	0.039	0.039	0.057	0.089	0.13	0.2
	B	0.031	0.046	0.074	0.097	0.13	0.18	0.25
SO_4	A	11	17	23	29	35	41	45
	B	12	17	24	30	35	41	46
Sr	A	22	31	31	35	39	41	43
	B	24	35	42	46	48	51	53
Zn	A	0.7	1.7	1.7	1.7	2.2	2.2	2.3
	B	0.67	1.3	1.6	1.7	1.8	1.8	1.8

TABLE D-15. CUMULATIVE PERCENT OF TOTAL SOLIDS CONTENT LEACHED ON SUCCESSIVE REPETITIONS OF PROTOCOL STEP 2 FOR ALLIANCE AFBC WASTE

Element/ Species	Replicate	Step 2 Repetition								
		1	2	3	4	5	6	7	8	9
Al	A	0.031	0.042	0.092	0.16	0.22	0.3	0.35	0.43	0.54
	B	0.04	0.045	0.093	0.17	0.24	0.33	0.4	0.5	0.61
B	A	7.1	8.9	23	42	60	79	92	110	130
	B	10	12	26	49	68	96	110	130	150
Ba	A	0.91	1.2	1.3	1.4	1.5	1.6	1.8	2	1.2
	B	0.88	0.88	1	1	1.1	1.1	1.2	1.4	1.5
Be	A	0.63	0.63	1.9	4.0	5.6	7.5	7.5	7.5	7.5
	B	1	1	2.3	4.8	6.7	9.8	9.8	9.8	9.8
Ca	A	9	13	20	24	28	35	39	43	46
	B	9.4	14	20	24	28	36	39	42	46
Cl	A	76	84	84	84	84	84	84	84	84
	B	79	87	87	87	87	87	87	87	87
Co	A	5.6	6.6	16	29	40	53	62	73	90
	B	8.3	10	19	35	47	67	77	91	110
Cr	A	3.2	4	8	14	19	24	28	34	41
	B	4	5	9	16	21	30	34	40	48
Cu	A	1.6	2.3	5.8	10	15	20	24	30	38
	B	2.5	3.2	6.6	13	17	24	30	36	45
F	A	3.7	4.7	6.7	7.5	8.6	9.3	10	11	12
	B	3.7	4.9	6.3	7.5	8.5	9.1	10	11	12
Fe	A	0.0014	0.0014	0.044	0.0064	0.0074	0.0094	0.011	0.013	0.015
	B	0.0016	0.0016	0.0036	0.0056	0.0066	0.0086	0.011	0.013	0.015
Mg	A	0.25	0.43	0.44	0.45	0.46	0.47	0.75	1.1	1.6
	B	0.52	0.78	0.79	0.8	0.8	0.81	1.1	1.5	2.1
Mn	A	0.027	0.035	0.068	0.11	0.15	0.19	0.23	0.27	0.33
	B	0.033	0.041	0.073	0.13	0.17	0.23	0.27	0.31	0.38
Mo	A	22	28	35	42	47	53	57	63	70
	B	25	31	38	47	53	62	67	72	80
Ni	A	2.5	2.5	5.1	9.1	12	16	18	22	26
	B	3.2	3.2	6	11	14	20	23	26	31
SO_4	A	17	26	35	45	53	62	71	79	88
	B	18	27	36	45	54	63	71	80	88
Si	A	0.016	0.02	0.033	0.046	0.06	0.072	0.084	0.1	0.12
	B	0.017	0.021	0.032	0.051	0.062	0.083	0.095	0.11	0.13
Sr	A	36	42	47	49	51	55	57	59	60
	B	39	45	49	51	53	57	58	60	61
Ti	A	0.12	0.17	0.38	0.66	0.91	1.2	1.5	1.8	2.3
	B	0.17	0.22	0.42	0.76	1	1.4	1.7	2.1	2.6
V	A	10	15	32	54	75	97	110	140	170
	B	14	20	35	63	85	120	140	160	200
Zn	A	0.54	0.54	1.2	2.1	2.8	3.7	4.1	4.7	5.6
	B	0.76	0.76	1.4	2.5	3.3	4.7	5.2	5.9	6.8

TABLE D-16. CUMULATIVE PERCENT OF TOTAL SOLIDS CONTENT LEACHED ON SUCCESSIVE REPETITIONS OF PROTOCOL STEP 2 FOR GEORGETOWN AFBC WASTE

Element/ Species	Replicate	Step 2 Repetition								
		1	2	3	4	5	6	7	8	9
Ba	A	2.2	2.9	20	33	40	47	51	56	62
	B	2.3	3.1	21	33	41	48	53	57	65
Ca	A	9.1	13	16	19	21	24	26	29	31
	B	9.1	13	16	19	21	24	26	29	31
Cl	A	71	71	71	71	71	71	71	71	71
	B	79	79	79	79	79	79	79	79	79
F	A	0.7	0.87	1.2	1.5	1.5	1.7	2	2.3	2.6
	B	0.77	1	1.4	1.9	2.1	2.4	2.6	2.9	3.2
K	A	6.8	9.2	11	13	14	15	16	17	18
	B	6.8	9.2	11	13	14	15	15	16	18
Li	A	23	29	34	38	39	42	42	45	46
	B	24	31	35	38	40	43	43	43	44
Mg	A	1	1.1	1.2	1.2	1.2	1.3	1.3	1.5	1.5
	B	1.3	1.4	1.4	1.5	1.5	1.2	1.6	1.6	1.7
Na	A	8.7	9.7	13	15	16	17	18	19	21
	B	6.2	8.1	11	13	14	16	17	19	20
SO_4	A	30	40	<41	<41	<41	<41	<41	<41	<41
	B	33	45	<46	<46	<46	<46	<46	<46	<46
Si	A	0.093	0.13	0.17	0.18	0.19	0.2	0.22	0.24	0.24
	B	0.11	0.15	0.16	0.17	0.18	0.2	0.21	0.22	0.23
Sr	A	78	88	96	100	100	110	110	110	110
	B	74	84	92	96	99	100	100	100	100

* A value greater than the detection limit was reported for this substep.

of 10. Mean Step 1 concentrations for both barium and fluoride were highest for the Exxon PFBC waste (Tables D-8 to D-11).

TABLE D-17. CUMULATIVE PERCENT EXTRACTION COMPARISONS FOR THE THREE FBC WASTES AFTER SEVEN REPETITIONS OF PROTOCOL STEP 2*

Element/	Waste		
Species	Exxon PFBC	Alliance AFBC	Georgetown AFBC
Ba	7.2	1.5	52
Ca	31	39	26
Cl	38	86	75
F	18	10	2.3
Mg	0.05	0.94	1.4
Na	24	8.1	17
Si	0.22	0.09	0.21
SO_4	46	71	≤46
Sr	48	58	>100

*Averages for Replicates A and B.

While values could not be computed for all three FBC wastes, boron extraction was extremely high for two wastes (exceeding 100% for the Alliance AFBC waste), which certainly reflects some analytical abberation. This abberation most likely occurred in the solids analysis as a result of matrix interference in the analysis of the digest solution. This problem is evident for a few other elements as well.

Iron, manganese and aluminum were not particularly mobile on a percentage basis. Some other metals varied considerably from waste to waste; for example, chromium ranged from 2.45 to 31.3% and nickel ranged from 3.2 to 20.5%. For two wastes, cobalt was below detection limits, whereas for the other waste nearly 70% was extracted.

D.3.2.2 Protocol Step 3

The two items of importance for waste leaching are the concentrations of specific species and the duration of their release at a concentration high enough to be of concern. Investigation of concentration as a function of VPM data as represented in protocol Steps 1 and 2 (Figures D-9 to D-35) and the cumulative percent extracted in combination is an important means of assessing potential release of contaminants. However, in the field test experiments (see Appendix E), the VPM range represented by protocol Steps 1 and 2 is somewhat displaced from the VPM values encountered in the field situation. In protocol Step 3, replications result in a decrease rather than increase of VPM. Step 3 thus evaluates the potential for higher solute concentrations where solubility is not the limiting factor.

The Exxon PFBC and Alliance AFBC wastes were subjected to protocol Step 3, the former to two replications and the latter to six replications (final VPM of 3.33 and 1.43 respectively). Table D-18 provides a qualitative summary of the trends observed with increasing replications (decreasing VPM) for each element or species analyzed. Slight increases or constant concentrations imply solubility controls, whereas increases were probably related to changes in pH or increase in total ionic strength (which increases mass solubility) or both. Where significant increases occurred, sorption-desorption phenomena may have been controlling (including ion exchange) or total dissolution may have been at play where a species was contained in the solids in two forms. A portion of the species may be locked in the solid matrix in an insoluble or unavailable form while another is on the surface (or free) as a very soluble form that is completely dissolved. In the latter case, the resultant leachate concentration would be expected to be in direct proportion to the mass of waste solids contacted with a fixed volume of leaching solution. In terms of cumulative percent of total solids leached on successive replications, a constant value would be expected since all of the mobile fraction would be released into solution from each mass of solids.

Table D-19 contains the computations for percent of solids leached on successive repetitions of protocol Step 3 for Exxon PFBC and Alliance AFBC wastes. For the Exxon PFBC waste, Cl, Cr, Fe, and Na showed essentially constant percent recoveries for each step while for the Alliance AFBC waste, Cl, Cr, Co, Cu, Fe, K, and possibly Ti and V appeared to have constant recoveries. Examination of plots represented by Figures D-9 to D-35 shows

TABLE D-18. CONCENTRATION TRENDS OF EXTRACTABLE SPECIES UPON SUCCESSIVE LEACHING OF FRESH EXXON PFBC AND ALLIANCE AFBC WASTE (Steps 1 and 3)

	Change in Leachate Concentrations	
Element/ Species	Exxon PFBC 2 Repetitions of Step 3	Alliance AFBC 6 Repetitions of Step 3
Al	Slight decrease	Decrease then increase
B	Increase	Increase*
Ba	Increase	Increase
Be	-	Decrease then increase
Ca	Increase	Increase*
Cd	-	Increase
Cl	Increase	Increase
Co	-	Increase
Cr	Increase	Increase
Cu	-	Increase
F	Constant*	*
Fe	Slight decrease	Increase
Li	-	Increase
Mg	Constant	Constant
Mn	-	Increase
Mo	-	Increase
Na	Increase	Increase
Ni	-	Increase
pH	Increase	Constant
SO_4	Increase	Slight increase
Si	Decrease	Decrease then increase
Sp. Cond.	Increase	Increase
Sr	Increase	Increase
TDS	Increase	Increase
Ti	-	Increase
V	-	Increase*
Zn	Possible increase	Increase

* Data scatter.

TABLE D-19. CUMULATIVE PERCENT OF TOTAL SOLIDS CONTENT LEACHED ON SUCCESSIVE REPETITIONS OF PROTOCOL STEP 3 FOR EXXON PFBC AND ALLIANCE AFBC WASTES

		Step 3 Repetition							
		Exxon PFBC		Alliance AFBC					
Element/ Species	Replicate	1	2	1	2	3	4	5	6
Al	A	0.0085	0.0056	0.0093	–	0.012	0.011	0.011	0.0071
	B	0.0086	0.0046	0.011	0.0048	0.015	0.011	0.011	0.01
B	A	16	13	2.03	0.51	3.5	3	3.2	2
	B	16	13	3.5	0.87	4	3.1	3.2	2.9
Ba	A	2	1.1	0.14	0.07	0.12	0.11	0.08	0.083
	B	1.7	1.1	0.11	0.16	0.14	0.083	0.064	0.059
Ca	A	4.1	2.5	2.4	1.5	1.7	0.97	1.1	0.84
	B	4.1	2.5	2.3	1.5	1.3	1	0.61	0.56
Cd	A	–	–	74	16	65	57	62	37
	B	–	–	91	16	74	58	63	56
Cl	A	–	25	63	58	62	60	59	53
	B	27	27	58	59	62	60	60	56
Co	A	–	–	2.6	0.52	2.5	1.8	2.1	1.3
	B	–	–	3.3	0.74	2.6	2	2.2	1.9
Cr	A	0.34	0.79	1.2	1.1	1.8	1.5	1.5	1.2
	B	1.2	0.86	1.4	1.2	1.9	1.6	1.4	1.3
Cu	A	0.68	–	0.7	0.21	0.81	0.72	0.76	0.55
	B	–	–	0.87	0.26	0.92	0.77	0.76	0.70
F	A	10	1.4	1.1	0.31	0.45	0.29	0.21	0.15
	B	2.1	1.5	1.2	0.16	0.43	0.44	0.23	0.15
Fe	A	0.004	0.002	0.00025	0.00032	0.00027	0.00035	0.00027	0.00020
	B	0.003	0.002	0.00036	0.00051	0.00032	0.00027	0.00025	0.00026
K	A	–	–	8.9	10	9.7	9.8	9.3	11
	B	–	–	8.2	10	9.9	9.8	8.3	9.1
Mg	A	0.006	0.001	0.19	0.06	0.038	0.019	0.044	0.025
	B	0.003	0.001	0.18	0.066	0.045	0.0019	0.046	0.05
Mn	A	–	–	0.0092	0.0028	0.0079	0.0067	0.007	0.0045
	B	–	–	0.11	0.0039	0.0088	0.007	0.0072	0.0064
Mo	A	–	–	10	6.7	5.7	4.8	4.1	3.7
	B	–	–	9.8	6.9	6.1	4.7	3.8	3.5
Na	A	4	4.7	–	–	–	–	–	–
	B	4.6	4.5	–	–	–	–	–	–
Ni	A	–	–	0.91	0.28	0.71	0.58	0.63	0.41
	B	–	–	1.1	0.28	0.78	0.61	0.64	0.58
Si	A	0.0037	0.0021	0.0049	0.0019	0.0038	0.0027	0.0025	0.0018
	B	0.0063	0.0034	0.0051	0.0026	0.0035	0.0031	0.0025	0.0022
SO_4	A	2.6	1.9	4.4	3.1	2.2	1.9	1.7	1.3
	B	2.9	2	4.7	3.1	2.2	1.9	1.7	1.3
Sr	A	16	9.1	11	12	14	8.4	8.9	7.4
	B	14	9.2	15	12	11	8.6	4.6	4.3
Ti	A	–	–	0.05	0.018	0.048	0.042	0.044	0.028
	B	–	–	0.061	0.022	0.055	0.045	0.044	0.041
V	A	–	–	4.3	1.4	3.7	3.4	3.6	2.2
	B	–	–	5.1	1.7	4.3	3.7	3.5	3.2
Zn	A	0.36	0.13	0.23	0.15	0.17	0.14	0.15	0.13
	B	0.36	0.13	0.3	0.17	0.18	0.14	0.16	0.14

that other species, like lithium and sodium (Alliance AFBC waste) had solids analysis values that were below detection limits and percent extractions could therefore not be computed.

Calcium and sulfate values for both wastes decreased with successive extractions nearly in direct proportion with the VPM ratio indicating solubility limits were reached with the Step 1 extraction. Other species with decreasing percent extractions through Step 3 were F, Fe (Exxon), Mo (Alliance), Ni (Alliance), Si, Sr, and Zn.

D.3.3 Comparison of One-, Two-, and Seven-Day Leaching Results

Tables D-20 to D-23 contain the summary statistics for Exxon PFBC and Alliance AFBC Step 1 leachates with two- and one-day extraction duration. While six replicate samples were prepared in each case, not all samples yielded measurable values for all species. An accounting of the total number of observations and those observations that were less than the detection limit value (set equal to zero) is also given in each table. Fewer data are available for Step 2 and 3 leachates of one-day duration for the Exxon PFBC waste.

For Step 1, comparison of the mean or median concentration of individual species for each waste and for the three different extraction times reveals no clear pattern of concentration change with duration of the extraction. The values are either essentially the same magnitude or the intermediate extraction time (two days) value is higher (or lower) than the seven- and one-day values. For several species with each of the wastes, however, a trend of increasing or decreasing mean (or median) concentration is indicated. Table D-24 summarizes the time-of-leaching results in a qualitative fashion. These trends have not been tested statistically for significance and some apparent increases are quite small, such as the copper and chromium values. In several cases, the median followed a different trend from the mean for a given waste. In only a few instances was the same behavior seen for both the Exxon PFBC and Alliance AFBC waste. Only chromium and sodium increased in concentration as extraction time increased for

TABLE D-20. SUMMARY STATISTICS FOR STEP 1, TWO-DAY EXTRACTION OF EXXON PFBC WASTE[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	5	0	0.7	0.6	0.5	1.1	0.2
As	4	4	0	0	0	0	0
B	5	0	13	12	12	14	0.9
Ba	5	0	0.3	0.3	0.2	0.3	0
Ca	5	0	890	1180	0.2	1760	710
Cd	5	5	0	0	0	0	0
Cl	6	0	8.6	7.5	4.9	16	3.9
Co	5	5	0.1	0.1	0.1	0.1	0
Cr	5	5	0	0	0	0	0
Cu	5	5	0	0	0	0	0
F	6	0	1	0.9	0.9	1.1	0.1
Fe	5	0	0.3	0.2	0.2	0.4	0.1
K	5	5	20	20	20	20	0
Li	0	0	-	-	-	-	-
Mg	5	0	0.9	0.2	0.1	3	1.3
Mn	5	5	0	0	0	0	0
Na	5	4	3.5	2.5	2.5	7.4	2.2
Ni	5	5	0	0	0	0	0
Pb	4	4	0	0	0	0	0
pH[2]	6	0	12.2	12.2	12.1	12.2	0
Se	4	4	0.1	0.1	0.1	0.1	0
Si	5	0	0.6	0.6	0.4	1	0.2
SO_4	6	0	1570	1570	1370	1800	181
Sp. Cond.[3]	6	0	24700	10000	10000	9800	35900
Sr	5	0	2.3	1.8	1.7	4.1	1.0
TDS	5	0	3650	3680	2920	4110	460
TOC	2	0	3.7	3.7	1.4	6	3.3
Ti	5	5	0	0	0	0	0
V	5	5	0	0	0	0	0
Zn	5	0	0.3	0.3	0.1	0.4	0.1

[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] Units are micromhos/cm.

TABLE D-21. SUMMARY STATISTICS FOR STEP 1, TWO-DAY EXTRACTION OF ALLIANCE AFBC WASTE[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	6	0	0.7	0.71	0.63	0.76	0.042
B	6	0	2.5	2.5	2.2	2.8	0.22
Ba	6	0	0.22	0.22	0.21	0.22	0.004
Be	6	0	0	0	0	0	0
Cd	6	0	0.03	0.03	0.03	0.04	0.003
Cl	6	0	53	53	51	57	2.3
Co	6	0	0.06	0.05	0.05	0.06	0.006
Cr	6	0	0.1	0.1	0.08	0.11	0.008
Cu	6	0	0.07	0.07	0.06	0.07	0.005
F	6	0	0.36	0.36	0.25	0.44	0.071
Fe	6	0	0.05	0.05	0.04	0.5	0.003
K	6	0	19	19	16	20	1.3
Li	6	0	0.15	0.15	0.13	0.15	0.008
Mg	6	6	0.2	0.02	0.02	0.02	0.000
Mn	6	0	0.01	0.01	0.01	0.01	0.001
Mo	6	0	0.31	0.32	0.28	0.33	0.018
Na	6	0	6	6.1	5.5	6.3	0.29
Ni	6	0	0.09	0.09	0.08	0.11	0.008
pH[2]	6	0	12.3	12.3	12.2	12.3	0.041
Si	6	0	0.6	0.56	0.51	0.83	0.12
SO_4	6	0	1420	1420	1350	1490	61
Sp. Cond.[3]	6	0	9390	9400	9300	9450	49
TDS	6	0	4110	4110	3940	4260	110
Ti	6	0	0.18	0.18	0.16	0.2	0.012
TIC	0	0	-	-	-	-	-
TOC	1	0	0.6	0.6	0.6	0.6	-
V	6	0	0.17	0.16	0.15	0.18	0.011
Zn	6	0	0.04	0.04	0.04	0.05	0.005

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE D-22. SUMMARY STATISTICS FOR STEP 1, ONE-DAY EXTRACTION OF EXXON PFBC WASTE[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	6	0	0.9	0.9	0.4	1.7	0.55
As	6	6	0	0	0	0	0
B	6	0	8.1	8	7.6	8.6	0.33
Ba	6	0	0.2	0.2	0.1	0.3	0.07
Ca	6	0	1460	1580	820	1640	320
Cd	6	6	0	0	0	0	0
Cl	5	0	4.9	4.3	4.3	6	0.86
Co	6	6	0.1	0.1	0.1	0.1	0
Cr	6	6	0	0	0	0	0
Cu	6	6	0	0	0	0	0
F	6	0	1.1	1.1	1	1.1	0.028
Fe	6	0	0.3	0.3	0.1	0.6	0.21
K	6	6	20	20	20	20	0
Mg	6	0	2.6	2.2	0.1	6.1	2.7
Mn	6	6	0	0	0	0	0
Na	6	6	2.5	2.5	2.5	2.5	0
Ni	6	6	0	0	0	0	0
Pb	6	6	0	0	0	0	0
pH[2]	6	0	12.0	12.1	11.9	12.1	0.079
Se	6	6	0.1	0.1	0.1	0.1	0
Si	6	0	1.2	1.1	0.6	2.4	0.66
SO_4	6	0	1590	1550	1330	1970	230
Sp. Cond.[3]	6	0	11000	11000	10500	11000	200
Sr	6	0	1.4	1.4	1.3	1.5	0.044
TDS	6	0	3800	4100	2710	4150	570
Ti	6	6	0	0	0	0	0
TOC	2	0	1.6	1.6	1	2.2	0.88
V	6	6	0	0	0	0	0
Zn	6	0	0.5	0.5	0.4	0.6	0.075

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE D-23. SUMMARY STATISTICS FOR STEP 1, ONE-DAY EXTRACTION OF ALLIANCE AFBC WASTE[1]

Element/ Species	Number of Observations	Number of Values at Detection Limit	Mean	Median	Minimum	Maximum	Standard Deviation
Al	6	0	0.7	0.6	0.5	0.9	0.16
B	6	0	2.5	2.4	2	3.2	0.51
Ba	6	0	0.2	0.2	0.2	0.2	0.026
Be	6	0	0	0	0	0	0.001
Cd	6	0	0	0	0	0	0.006
Cl	6	0	51	50	48	57	3.3
Co	6	0	0.1	0.1	0	0.1	0.01
Cr	6	0	0.1	0.1	0.1	0.1	0.014
Cu	6	0	0.1	0.1	0.1	0.1	0.012
F	6	0	0.3	0.3	0.3	0.5	0.10
Fe	6	0	0.1	0	0	0.1	0.021
K	6	0	11	11	8.9	12	1.1
Li	6	0	0.1	0.1	0.1	0.1	0.008
Mg	6	6	0	0	0	0	0
Mn	6	0	0	0	0	0	0.002
Mo	6	0	0.3	0.3	0.3	0.3	0.019
Na	6	0	3.9	3.9	3.5	4.1	0.22
Ni	6	0	0.1	0.1	0.1	0.1	0.01
pH[2]	6	0	12.2	12.2	12.2	12.3	0.055
Si	6	0	0.8	0.6	0.5	1.6	0.43
SO_4	6	0	1560	1550	1500	1640	63
Sp. Cond.[3]	6	0	10020	10000	10000	10100	41
TDS	6	0	3900	3850	3720	4120	160
Ti	6	0	0.2	0.2	0.1	0.2	0.033
TOC	3	0	0.7	0.7	0.7	0.7	0
V	6	0	0.2	0.2	0.1	0.2	0.032
Zn	6	0	0	0	0	0.1	0.007

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE D-24. SUMMARY OF EFFECTS OF EXTRACTION DURATION ON LEACHATE SPECIES CONCENTRATIONS FOR PROTOCOL STEP 1

Element/ Species	Concentration Trend with Increasing Extraction Time			
	Exxon PFBC		Alliance AFBC	
	Mean	Median	Mean	Median
Al	None	None	Increase	Increase
B	None	None	Increase	Increase
Ba	None	None	None	None
Ca	None	None	ID	ID
Cd	ID*	ID	Increase	Increase
Cl	None	None	None	None
Co	Increase	None	None	None
Cr	Increase	Increase	Increase	Increase
Cu	Increase	None	None	None
F	Decrease	Decrease	None	None
Fe	Decrease	Decrease	None	Increase
K	Increase	None	Increase	Increase
Li	ID	ID	Increase	Increase
Mg	None	None	Increase	Increase
Mn	None	None	Increase	Increase
Mo	ID	ID	Increase	Increase
Na	Increase	Increase	Increase	Increase
Ni	ID	ID	None	None
pH	None	None	None	None
Se	ID	ID	ID	ID
Si	None	None	Decrease	Decrease
SO_4	Decrease	Decrease	Decrease	Decrease
Sp. Cond.	None	None	Decrease	Decrease
Sr	Increase	Increase	ID	ID
TDS	Decreae	Decrease	None	None
Ti	Increase	None	None	None
TOC	None	None	None	None
V	None	None	None	None
Zn	Decrease	Decrease	None	None

*ID = Insufficient data.

both wastes and for both the mean and median values. Only sulfate showed a consistent decrease in concentration as extraction time increased. It is apparent that there is no clear and universal association between leachate concentration and the time of extraction for the Exxon PFBC and Alliance AFBC wastes.

Table D-25 summarizes a comparison of seven-day and one-day extraction times for protocol Steps 2 and 3 with the Exxon PFBC waste. Only sodium and silicon showed a consistent change for all three extraction categories; the sodium values increased and the silicon values decreased. All other species showed no change with extraction time or different behavior from step to step. As with the Step 1 data, the need for a seven-day extraction period is not clearly supported. In some cases, apparent decreases in concentration occurred.

TABLE D-25. COMPARISON OF CONCENTRATIONS IN ONE-DAY AND SEVEN-DAY EXTRACTS FROM PROTOCOL STEPS 2 AND 3 LEACHING OF EXXON PFBC WATSE

Element/ Species	Concentration Trend with Increasing Extraction Time		
	Step 2 Repetition 1	Step 2 Repetition 2	Step 3 Repetition 1
Al	Increase	Increase	Decrease
B	Increase	Increase	None
Ba	Decrease	None	Increase
Ca	Decrease	Increase	Increase
Cl	Negligible	ID	Decrease
Cr	ID*	Increase	ID
F	Decrease	None	Increase
Fe	Increase	None	Decrease
Mg	Increase	Decrease	Increase
Na	Increase	Increase	Increase
pH	None	None	None
Si	Decrease	Decrease	Decrease
SO_4	None	None	Decrease
Sp. Cond.	Decrease	Increase	Decrease
Sr	Increase	Increase	None
TDS	Decrease	None	Increase
Zn	Decrease	Increase	Decrease

* Based on comparison of average values for duplicate samples.
ID = Insufficient data.

D.4 Disposal Media Leaching Behavior

In order to assess the contribution to (rather than attenuation of) contaminants to FBC waste leachate, both batch leaching and column leaching studies were performed on disposal media. These investigations were also performed to provide a basis of comparison of the leaching characteristics of the FBC wastes and the soils.

D.4.1 Batch Leaching

Protocol Step 1 was performed on each of the disposal media with deionized water as the eluant. Table D-26 presents the data for each of the media. Comparison of these values with the mean and median values of Step 1 leachates of the Exxon PFBC, Alliance AFBC and Georgetown AFBC wastes (Tables D-8, D-10 and D-11 respectively) shows that in numerous instances, the soil leachate concentrations are roughly equal to or greater than the values for the waste leachates. A qualitative summary is presented in Table D-27. The most significant contributor of contaminants was the mine interburden leachate, where values for heavy metals consistently exceeded those from the waste leachates. For the other soils, magnesium, manganese and silicon were consistently higher. Frequently, greater fluoride and organic carbon were extracted from the soils than from the wastes. Much higher inorganic carbon values in the soil leachate compared to the Georgetown waste extract (the only waste evaluated for inorganic carbon) likely reflects limitation of carbonate in the high pH waste extract by the high calcium content and precipitation of calcium carbonate.

Table D-28 presents data from an earlier and more limited soil extraction study. These data are compared to the data of Table D-26 in a qualitative manner. While some differences are found, values rarely differed by much more than a factor of 2 except for potassium concentrations, where earlier data are 10 to 25 times greater for the three media studied.

Tables D-29 and D-30 contain the average (of two replicates) concentrations for Step 2 replicates conducted on the shale and sandstone media

TABLE D-26. CONCENTRATION DATA FOR PROTOCOL STEP 1 EXTRACTION OF DISPOSAL MEDIA

Element/ Species	Concentration (mg/L)[1]					
	Shale	Interburden	Sandstone	Glacial Till	Alluvium	Limestone
Al	<0.25	<0.25	<0.25	<0.25	<0.25	~0.3
B	0.06	~0.07	<0.045	~0.05	<0.045	<0.045
Ba	0.12	0.092	0.056	0.14	0.071	0.12
Ca	52	28	73	22	1	9.9
Cd	<0.04	<0.04	<0.042	<0.04	<0.04	<0.04
Cl	<2	<2	<2	<2	<2.0	4.1
Co	<0.03	0.15	~0.04	<0.03	<0.03	<0.03
Cr	~0.015	0.088	0.005	<0.005	<0.005	<0.005
Cu	<0.005	0.088	0.005	<0.005	<0.005	<0.005
F	0.39	0.13	0.34	1	0.09	1
Fe	0.055	0.24	<0.04	<0.04	<0.04	<0.04
K	4.7	4.8	7.8	<0.22	<0.21	7.8
Li	~0.006	0.034	0.035	<0.002	<0.002	<0.002
Mg	7.1	9.7	22	4.4	<0.17	2.6
Mn	0.13	0.19	0.63	<0.006	0.029	<0.006
Mo	<0.01	<0.01	<0.01	~0.015	<0.01	~0.2
Na	2.1	1.4	1.6	3.5	1.6	13
Ni	0.07	0.26	<0.015	<0.015	~0.02	0.033
pH[2]	8	5.5	7.7	8.2	5.9	8.7
Si	3.7	14	4.9	3.9	5.5	3.4
SO_4	68	140	170	15	4.5	45
Sp. Cond.[3]	350	300	500	150	40	210
Sr	0.13	0.2	0.18	0.007	<0.002	0.33
TDS	170	230	430	~40	15	130
Ti	<0.025	<0.025	0.05	<0.025	<0.025	<0.025
TIC	24	2	21	14	<2	12
TOC	2	0.62	0.7	4.7	2.3	1.2
V	<0.015	<0.015	0.02	<0.015	<0.015	<0.015
Zn	~0.02	0.255	0.015	~0.015	<0.015	<0.015

[1] Averages of two values.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE D-27. SUMMARY OF DISPOSAL MEDIA STEP 1 LEACHATE CONCENTRATIONS THAT WERE GREATER THAN OR EQUAL TO STEP 1 WASTE LEACHATE CONCENTRATIONS

Element/ Species	Disposal Medium																	
	Shale			Interburden			Sandstone			Glacial Till			Alluvium			Limestone		
	EP[1]	AA[2]	GA[3]	EP	AA	GA	EP	AA	GA	EP	AA	GA	EP	AA	GA	EP	AA	GA
Al																		
B																		
Ba		X[4]									X						X	
Ca																		
Cd																		
Cl																X		
Co				X	X	X			X									
Cr				X	X	X												
Cu				X		X												
F		X	X					X	X	X	X	X				X	X	X
Fe			X	X	X	X												
K																		
Mg	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Mn		X	X	X	X	X	X	X	X						X			
Mo																		X
Na																	X	X
Ni			X	X	X	X												
pH																		
Si	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SO_4																		
Sp. Cond.																		
Sr																		
TDS																		
Ti																		
TIC	ND[5]	ND	X	ND	ND		ND	ND	X	ND	ND	X	ND	ND		ND	ND	X
TOC	X	X								X	X	X	X	X			X	
V				X					X									
Zn			X			X												

[1] EP = Exxon PFBC Waste

[2] AA = Alliance AFBC Waste

[3] GA = Georgetown AFBC Waste

[4] X = Soil extract value greater than or equal to waste value for that species.

[5] ND = No data.

TABLE D-28. "EARLY STUDY" STEP 1 LEACHATE CONCENTRATIONS FOR SELECTED GROUND DISPOSAL MEDIA SAMPLES AND RELATIONSHIP TO "LATER STUDY" STEP 1 MEDIA EXTRACTIONS

	Medium					
	Shale		Sandstone		Interburden	
Element/ Species	Concentration (mg/L)	Relationship to New Data	Concentration (mg/L)	Relationship to New Data	Concentration (mg/L)	Relationship to New Data
Al	0.3	0	0.45	+	0.54	+
B	0.24	+	0.059	+	0.14	+
Ba	0.3	0	0.25	+	0.23	+
Ca	72	0	64	0	43	+
Cd	<0.005	0	<0.005	0	<0.005	0
Co	<0.15	0	0.34	+	0.69	0
Cr	<0.005	0	0.016	0	0.015	–
Cu	0.005	0	<0.005	0	0.063	0
F	0.26	0	0.26	0	<0.1	0
Fe	0.069	0	0.13	+	1.3	+
K	46	+	120	+	120	+
Mg	10	0	19	–	17	+
Mn	0.19	0	0.36	0	0.38	+
Mo	<0.04	0	0.27	+	0.27	+
Na	<5	0	<5	0	5	0
Ni	<0.02	–	0.028	+	0.65	+
Si	8.4	+	10	+	28	+
SO_4	81	0	160	0	190	+
Sr	0.2	0	0.19	0	0.37	0
Ti	–		0.015	+	0.019	0
V	0.051	+	0.13	+	0.13	+
Zn	<0.002	0	<0.002	0	0.77	+

+ = value higher in earlier study
0 = value roughly the same in both studies
– = value lower in earlier study

TABLE D-29. CONCENTRATIONS OF PROTOCOL STEP 2 LEACHATES FROM SHALE DISPOSAL MEDIUM[1]

Element/ Species	Step 2 Repetition[2]					
	1	2	3	4	5	6
Al	0.4	0.48	0.28	1.9	1.6	2.4
B	0.5	0.95	0.77	0.59	1.1	0.22
Ba	0.61	0.78	0.68	0.62	0.82	0.41
Ca	32	26	22	22	21	21
Co	–	–	–	–	–	0.033
Cr	–	–	–	–	0.012	0.03
Cu	–	–	–	–	0.015	0.03
F	0.33	0.31	0.22	0.16	0.16	0.14
Fe	–	–	0.52	0.47	0.24	0.68
K	3.5	2.2	2.2	2.3	1.7	1.9
Mg	4	2.9	2.5	2.4	2.3	2.7
Mn	0.048	0.03	<0.06	–	–	–
Na	0.38	0.8	0.7	0.66	1.1	1.7
Ni	0.02	<0.02	0.03	0.035	0.045	<0.015
pH[3]	8.2	7.9	8	8.4	8.2	7.6
Si	2.2	1.9	2.9	2.6	1.8	2.9
SO_4	30	13	11	10	12	10
Sp. Cond.[4]	220	150	140	140	140	120
Sr	0.085	0.071	0.064	0.056	0.059	0.023
TDS	240	150	140	100	150	150
TIC	14	11	9.5	8.9	8.5	8.2
TOC	–	–	3.1	2.3	3.1	3.1
Ti	–	–	–	–	–	0.037
V	–	–	–	–	–	0.022

[1] Concentrations are in mg/L.

[2] Average of two replicate values.

[3] Units are standard pH units.

[4] Units are micromhos/cm.

TABLE D-30. CONCENTRATIONS OF PROTOCOL STEP 2 LEACHATES FROM SANDSTONE DISPOSAL MEDIUM[1]

Element/ Species	Step 2 Repetition[2]					
	1	2	3	4	5	6
Al	0.52	0.86	0.62	1	0.81	1
B	0.97	0.88	1.2	0.70	1.3	0.22
Ba	0.92	0.88	1.1	0.89	1.1	0.65
Ca	31	27	24	23	20	19
Cr	–	–	–	–	–	0.032
Cu	–	–	–	–	–	0.046
F	0.28	0.2	0.16	0.11	0.13	0.15
Fe	–	0.092	0.044	0.045	0.042	0.042
K	6	4.3	3.4	3.4	3.1	4.6
Mg	8.4	7.1	6.3	6.2	5.7	6.3
Mn	0.19	0.13	0.14	0.15	0.18	0.21
Na	1.7	0.46	0.8	0.69	1.3	1.9
Ni	0.026	0.02	0.03	0.036	0.025	0.03
pH[3]	8.1	7.9	7.9	7.9	8.2	7.7
Si	3.2	2.8	2.5	2.3	2.3	4
SO_4	44	31	24	24	21	24
Sp. Cond.[4]	240	180	190	170	140	150
Sr	0.099	0.088	0.082	0.076	0.073	0.04
TDS	320	310	240	120	170	77
Ti	–	–	–	–	–	0.055
TIC	14	11	8.6	12	10	9.2
TOC	–	–	5.4	1.5	1.8	1.1
V	–	–	–	–	–	0.16

[1] Concentrations in mg/L.

[2] Average of two replicate values.

[3] Units are standard pH units.

[4] Units are micromhos/cm.

respectively. Only data for those elements or species for which results are above detection limits are presented. Most species were constant or gradually declined upon repeated extractions. Aluminum concentrations increased for both soils with successive extractions. Some trace metals became measurable after 6 or 7 extractions. These data could be considered baseline values for the repeated laboratory attenuation studies (Protocol Steps 4 and 5) for the two soils.

D.4.2 Percent of Disposal Media Solids Content Extracted by Protocol Step 1

Table D-31 shows the percent of total solids leached from the disposal media by Step 1 leaching. Several species were extracted for a single leaching from the disposal media in high percentage relative to the bulk soil composition. Greater than 8 to 10 percent removal was arbitrarily designated high percentage. Sulfate removal was high for all media, especially the glacial till, alluvium and limestone. Molybdenum and cobalt removals were high for shale and interburden (data not presented for other media) while calcium removal was high only for sandstone and alluvium.

Moderate removals (say, 1 to 2 percent) of the bulk solids was seen for many more species and soils. Cr, Cu, Sr, Na, and Zn were roughly in this range for all six media. Calcium removal was moderate for shale only. Magnesium was moderate for all media but glacial till, where removal was of the order of 0.5 percent. Manganese was moderate only for the limestone. Lithium was moderate only for the glacial till, although values for the other media were only slightly lower.

While the percent extraction values were moderate to high for some species for some of the soils, the absolute concentrations were generally low compared to the waste leachates. Subsequent leaching steps for the shale and sandstone media removed additional quantities of the more readily mobilized species at slightly decreased percentages implying for calcium and sulfate at least that complete leaching of these species is likely after

TABLE D-31. PERCENT OF TOTAL SOLIDS CONTENT LEACHED FROM THE DISPOSAL MEDIA DURING PROTOCOL STEP 1 LEACHING

Element/ Species		Percent of Total Leached					
		Shale	Interburden	Sandstone	Glacial Till	Alluvium	Limestone
Al	A	–	–	–	–	–	–
	B	0.0035	0.0033	0.0035	0.0053	0.008	0.022
B	A	0.12	0.34	0.3	0.63	0.072	0.42
	B	0.15	0.45	0.4	0.83	0.096	0.56
Ba	A	0.19	0.098	0.18	0.32	0.17	1.6
	B	0.21	0.11	0.2	0.35	0.71	1.73
Be	A	0.4	0.52	0.34	0.51	0.59	1.7
	B	0.67	0.86	0.57	0.85	0.98	2.8
Ca	A	2.8	0.0059	8.2	0.55	22	0.1
	B	2.7	0.0057	8	0.53	21	0.095
Co	A	4.9	6.6	–	–	–	–
	B	7.5	10	–	–	–	–
Cr	A	0.72	0.56	0.74	0.89	1.1	1.2
	B	0.81	0.81	1.1	1.3	1.6	1.7
Cu	A	1.2	0.89	1.1	1	1.5	1.6
	B	1.3	0.92	1.2	1.1	1.6	1.7
Fe	A	0.0035	0.63	0.0034	0.0043	0.0049	0.02
	B	0.0035	0.63	0.0034	0.0043	0.0049	0.02
K	A	0.23	0.38	0.21	0.26	0.53	0.84
	B	0.23	0.37	0.21	0.26	0.52	0.83
Li	A	0.55	0.24	0.44	1.5	0.75	–
	B	0.54	0 24	0.43	1.5	0.74	–
Mg	A	1.1	2.3	1.3	0.55	3.1	0.85
	B	1.1	2.2	1.2	0.53	3	0.82
Mn	A	0.33	0.075	0.48	0.48	0.4	1.4
	B	0.31	0.071	0.45	0.45	0.38	1.3
Mo	A	14	13	–	2.2	–	–
Na	A	1.4	0.61	1.4	0.91	1.1	3.3
	B	1.1	0.48	1.1	0.73	0.9	2.6
Ni	A	2.5	2	2.8	2.5	5.7	7.9
	B	2.1	1.7	2.3	2.1	4.8	6.7
Si	A	2.4	0.03	0.022	0.025	0.016	0.14
	B	2.5	0.03	0.023	0.026	0.017	0.144
SO_4	A	21	12	14	<74	<74	62
	B	20	11	14	<73	<73	61
Sr	A	1	0.96	1.6	1.3	2.4	0.46
	B	1	3.8	6.2	5.2	9.5	1.8
Ti	A	0.012	0.017	0.02	0.025	0.024	0.085
V	A	0.30	0.28	0.28	0.28	0.43	0.45
Zn	A	1.5	1.6	0.15	0.16	0.27	0.44
	B	1.5	1.5	1.5	1.6	2.7	4.3

eight to twelve leaching steps (VPM = 80 to 120). For other species, it would not be prudent to extrapolate based on the limited data available.

D.4.3 Comparison of Waste and Disposal Media Composition and Leachate Concentration

The bulk solids composition of each disposal medium and the three wastes were tabulated for comparison (Table D-32). The most interesting aspect of these data is the similarity in composition among the soils and the wastes. Except for calcium and sulfate (and, to a lesser extent, aluminum), the elemental compositions were not extremely different. The differences among the soils and the wastes were about the same as among the three wastes. The similarities in soil leachates and the FBC leachates were consistent with the solids compositions for most elements.

Table D-33 provides a summary of Step 1 leachate concentration comparisons for the three FBC wastes and the six disposal media extracts. If the tabular value is greater than unity, the waste Step 1 value is greater than that of the media extract. For some species, the waste values were considerably higher. Species for which the waste/media ratio was of the order of ten or greater were calcium, sulfate and strontium for all media and for all three wastes. Sodium ranged from 2 to 12 in general. Other species' ratios were high for certain wastes and/or certain soils. Boron ratios were high for the Exxon and Alliance wastes for all media. Copper ratios were high for the Alliance waste only with sandstone and limestone. Potassium was high for the Exxon waste, lithium for the two AFBC wastes, and molybdenum for the Exxon waste with glacial till.

Some species showed higher leachate concentrations (ratio <1) from the disposal media. Notable in this regard were magnesium, manganese and silicon where on occasion the ratio dropped to less than 0.1. In some cases the zinc ratio was less than 1. The balance of the values were between these limits but generally greater than 1.

TABLE D-32. BULK SOLIDS COMPOSITION OF THE FBC WASTES AND DISPOSAL MEDIA

Element/ Species	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Shale	Interburden	Sandstone	Glacial Till	Alluvium	Limestone
Al (g/100g)	2.4	2.0	3.0	9.4	9.9	9.5	6.2	4.1	1.5
Ca "	22	31	32	1.1	0.53	0.38	5.7	0.14	32
Fe "	3.0	5.3	2.8	4.2	2.3	4.3	3.4	3.0	0.72
K "	2.2	0.42	0.50	2.7	1.7	3.0	2.4	1.2	0.75
Mg "	12	0.47	0.46	0.85	0.4	0.74	1.7	0.30	1.1
Si "	5.2	4.2	5.8	24	19	26	23	35	4.1
SO_4 "	23	12.7	0.46	0.36	0.64	0.53	<0.1	<0.10	0.12
B (mg/kg)	190	<2.25	390	130	130	130	74	60	47
Ba "	87	290	160	500	960	530	300	150	60
Be "	8.6	4.8	14	7.5	5.8	8.7	5.9	5.1	1.8
Cd "	0.44	0.17	—	0.13	0.19	0.11	0.15	0.11	0.13
Cl "	280	840	370	<40	<40	54	48	<40	120
Co "	13	9.0	9.2	20	<15	<15	15	<15	<15
Cr "	130	32	73	81	100	78	65	52	50
Cu "	59	38	27	37	51	40	44	30	28
Li "	<2.5	<2.5	39	55	130	68	20	40	<2.5
Mn "	130	600	290	750	3300	520	530	620	180
Mo "	26	27	7.4	<2.4	<2.4	<2.4	14	<2.4	<2.4
Na "	5200	<13.3	1400	3100	6900	3000	4600	3700	1290
Ni "	56	41	16	48	60	43	48	21	15
Sr "	160	820	260	170	180	110	130	70	370
Ti "	1590	1500	1800	5500	5400	4700	3660	3900	1080
V "	130	17	51	130	150	140	140	92	89
Zn "	290	68	34	94	90	92	87	51	32

TABLE D-33. RATIO OF FBC WASTE CONCENTRATION TO DISPOSAL MEDIA CONCENTRATION FOR PROTOCOL STEP 1 LEACHATES

	Shale			Interburden			Sandstone			Glacial Till			Alluvium			Limestone		
Element Species	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC
Al	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	180	59	2.7	150	51	2.3	-	-	-	210	71	3.2	-	-	-	-	-	-
Ba	1.7	1.1	1.6	2.2	1.4	2.1	3.6	2.3	3.4	1.4	0.93	1.4	2.8	1.8	2.7	1.7	1.1	1.75
Ca	32	26	29	61	49	55	23	18	21	78	62	70	1670	1340	1500	170	140	150
Cd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	12	5.87
Co	-	-	-	4.1	0.55	0.069	15	2	0.25	-	-	-	-	-	-	-	-	-
Cr	6	8	3.3	0.67	0.89	0.37	5	6.7	2.8	-	-	-	-	-	-	-	-	-
Cu	-	-	-	0.23	1.6	0.34	4	28	6	-	-	-	-	-	-	-	-	-
F	2.5	0.64	0.41	7.7	2	1.3	2.8	0.74	0.47	0.93	0.24	0.16	11	2.8	1.8	0.91	0.24	0.15
Fe	3.5	1.5	0.36	0.81	0.34	0.085	-	-	-	-	-	-	-	-	-	-	-	-
K	54	9.4	3.8	52	9.1	3.7	32	5.6	2.3	-	-	-	-	-	-	32	5.6	2.3
Li	-	60	83	-	11	15	-	10	14	-	-	-	-	-	-	-	-	-
Mg	0.2	0.11	0.37	0.15	0.084	0.27	0.066	0.037	0.12	0.33	0.19	0.61	-	-	-	0.57	0.32	1
Mn	NC[a]	0.16	0.08	NC[a]	0.11	0.054	NC[a]	0.032	0.016	-	-	-	NC[a]	0.69	0.35	-	-	-
Mo	-	-	-	-	-	-	-	-	-	160	28	1.3	-	-	-	12	2.1	0.10
Na	8.2	6.3	3.1	13	9.8	4.8	10.6	8.1	4	5	3.8	1.9	11	8.3	4.1	1.4	1.1	0.52
Ni	1.1	1.6	0.57	0.31	0.43	0.16	-	-	-	-	-	-	4.0	5.5	2.0	2.4	3.3	1.2
Si	0.34	0.15	0.64	0.09	0.041	0.18	0.26	0.11	0.49	0.33	0.14	0.62	0.23	0.1	0.43	0.38	0.16	0.71
SO_4	18	16	21	8.7	8	10	7	6.4	8.2	80	74	93	270	250	310	27	25	32
Sp. Cond.	23	23	22	27	27	26	16	16	16	54	54	52	200	200	200	39	39	37
Sr	22	160	110	14	110	68	15	110	73	400	2900	1900	-	-	-	8.4	62	40
TDS	19	23	24	14	16	17	7.5	8.8	9.3	80	95	100	210	250	270	25	30	31
Ti	-	-	-	-	-	-	1	6.4	1.2	-	-	-	-	-	-	-	-	-
TOC	0.64	0.6	1.9	2.1	1.9	6.2	1.8	1.7	5.5	0.27	0.26	0.82	0.55	0.52	1.7	1.1	1	3.4
V	-	-	-	-	-	-	4.5	13	1	-	-	-	-	-	-	-	-	-
Zn	6.5	2	0.5	0.51	0.16	0.04	-	-	-	8.7	2.7	0.67	-	-	-	-	-	-

NC[a] = Not calculated; disposal media concentration at or below detection limit.

Furthermore, the waste composition is not necessarily a good predictor of the leachate composition. Table D-12 was essentially a presentation of the ratio of Step 1 leachate concentration to bulk solids concentration for each of the wastes. If the bulk solids data were an effective predictor of concentration then the ratio would be relatively constant for each of the wastes for a given species. It can be seen from Table D-12 and Tables D-14, D-15 and D-16 that for more species than not, the ratio varies widely among the three wastes.

D.4.4 Laboratory Control Column Leachates

As noted, the six laboratory control columns were approximately six feet long and six inches in diameter and contained disposal media only. The time series behavior of the composition of the leachate from the columns was examined from computer printer plots of the leachate data for each column. A summary of concentration ranges and trends over the leaching period is given in Table D-34. Raw data from the control columns are contained in Appendix J.

Of particular significance in Table D-34 are the generally much higher leachate concentrations for most of the constituents in the leachate from the columns compared to the disposal media batch leachates (Protocol Step 1). Comparison of Table D-34 with Table D-26 reveals that except for Ba, Cd, F, and Cl (and a few individual species for one or two disposal media only) the column leachate concentrations were generally a factor of five, or much more, greater than the Step 1 batch leachate values. The volume-per-mass ratios for all of the column samples were considerably less than 10, the ratio for protocol Step 1.

Table D-35 provides a qualitative summary of the relative magnitudes of batch and column concentrations for each leachate constituent for each of the six disposal media. Since the column values vary considerably, the assessment is not exact. However, a consistent pattern was observed; column values were much greater than would be predicted by batch leaching. Not all

TABLE D-34. SUMMARY OF CONCENTRATION BEHAVIOR OF LEACHATES FROM DISPOSAL MEDIA LABORATORY CONTROL COLUMNS[1]

Element/ Species	Shale		Interburden		Sandstone		Glacial Till		Alluvium		Limestone	
	Concentration Range	Trend	Concentration Range	Trend	Concentration Range	Trend	Concentration Range	Trend	Concentration Range	Trend	Concentration Range	Trend
Al	0.6-6	↱	1500-2430	↓	0.6-3.3	↑	0.2-3.2	↷	1.6-2.9	↓	0.08-3.7	↷
B	0.3-2.3	↷	9-20	↓	0-2.4	↷	0-2.1	↷	0-1.8	↓	0.6-2.7	↷
Ba	0.04-0.3	⇣	0-0.16	↓	0-0.6	↷	0.1-0.9	↺	0.06-0.76	↷	0.05-0.95	↷
Ca	600-1200	↓	400-574	↑	740-860	-	210-320	↷	12-28	↓	100-330	↓
Cd	0.04(1)*	-	1.1-2.9	↷	DL	-	DL	-	DL	-	0.29(1)*	-
Cl	0-3.5	↑	15	-	0-4	↑	0-6.5	↑	<2	-	<2	-
Co	0.3-0.5	↳	16-40	↓	0-0.16	↷	0-0.24	↷	0-0.27	↷	0-0.9	↷
Cr	0.16-0.5	↷	0-7.2	↷	0.05-0.3	↷	0.015-0.40	↷	0-0.4	↷	0.03-0.29	↷
Cu	0-0.4	↷	26-56	↓	0-0.2	↷	0-0.34	↷	0-0.35	↷	0.005-0.18	↷
F	0.1-0.6	↳	2-15	↳	0.06-0.9	↳	0.3-0.7	↳	0.04-0.15		1.3-1.9	
Fe	0.06-2.9	⇣	6500-8200	-	0.05-1.5	-	0.25-3.27	↷	0.2-7.6	↓	0.25-2.7	↓
K	68-340	↳	50-850	↓	40-200	↓	15-75	↳	5-9	↷	25-141	↓
Mg	0-630	↳	1150-2300	↓	80-220	-	46-85	↷	5-7	↷	61-107	↷
Mn	20-50	↳	34-67	↷	0.1-2	↺	0.3-3.4	↷	0.18-1.8	↳	0.12-1.1	↷
Mo	0.05-0.32	↷	1-10	↓	0.025-0.18	↷	0.01-0.32	↷	0-026	↷	0.8-1.3	↓
Na	17-41	⇣	0-130	↷	7-11		0.6-31	↱	3-5	-	227-721	↷
Ni	0-0.5	↺	28-80	↓	0-0.14	↺	0-0.08	↳	0-0.09	-	0-0.1	↓
pH	7-8	↳	1.9-2.4	-	7-8	-	7.2-8.2	-	4-8	-	7.5-8.5	-
Si	7-17	↷	72-145	↷	10-25	↳	19-39	↺	9.6-17	↓	11-43	↷
SO_4	1900-2900	↱	18000-58000	↓	1500-2000	↱	201-560	↳	18-30	-	390-4370	↳
Sp. Cond.	3000-11000	↷	10000-30000	↳	2600-4100	↳	800-1400	↳	95-120	-	1000-7000	↓
Sr	1.8-6	↳	0.6-1.4	↳	1.6-2.6	↳	0.3-0.9	↳	0.11-0.44	↓	6.4-8.2	-
TDS	4000-13600	↳	28000-90000	↓	3000-4950	↳	560-1200	↳	60-295	-	820-7800	↳
Ti	0.03-1.1	↷	0.15-1.0	↷	0.01-0.65	↷	0-0.97	↷	0-1.0	↷	0-1.1	↷
TOC	0-6.8	-	0-40	↓	0-12	↓	0-100	↓	0-30	↓	0-24	↳
V	0.4-0.9	↷	1.1-8.2	↷	0.3-0.5	↷	0.13-0.67	↷	0.5-0.7	↷	0.19-0.70	↷
Zn	0.02-0.5	↷	86-143	↓	0.02-0.09	↺	0-0.9	↷	0-0.19		0-0.12	↷

Symbols:
↑ - increase
↓ - decrease
⇡ ⇣ - net change with variation
No indicator means relatively constant.
↷ - reversal downward
↺ - reversal upward
↳ - decrease with leveling out
↱ - increase with leveling out
DL - detection limit

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[1] Concentrations are in mg/L unless otherwise noted.
[2] Only one measurable value.
[3] Units are standard pH units.
[4] Units are micromhos/cm.

TABLE D-35. COMPARISON OF MEDIA CONTROL COLUMN LEACHATE CONCENTRATIONS TO STEP 1 LEACHATE VALUES FOR THE SIX DISPOSAL MEDIA

Element/	Column Value Relative to Step 1 Value					
Species	Shale	Interburden	Sandstone	Glacial Till	Alluvium	Limestone
Al	+	+	+	+	+	+
B	+	+	+	+	+	+
Ba	0	0	+	0	+	0
Ca	+	+	+	+	+	+
Cd	0	+	0	0	0	0
Cl	0	+	0	0	0	0
Co	+	+	+	+	+	+
Cr	+	+	+	+	+	+
Cu	+	+	+	+	+	+
F	0	+	0	0	0	0
Fe	+	+	+	+	+	+
K	+	+	+	+	+	+
Mg	+	+	+	+	+	+
Mn	+	+	0	+	+	+
Mo	+	+	+	+	+	+
Na	+	+	+	0	0	+
Ni	+	+	+	+	0	0
pH	0	−[1]	0	0	0	0
Si	0	+	+	+	0	+
SO_4	+	+	+	+	+	+
Sp. Cond.	+	+	+	+	0	+
Sr	+	+	+	+	+	+
TDS	+	+	+	+	+	+
Ti	+	+	+	+	+	+
TOC	+	+	+	+	+	+
V	+	+	+	+	+	+
Zn	+	+	+	+	+	+

+ = Column value higher by ≃ factor of 3 to 4 or greater.
0 = Roughly equivalent ± factor of 3 to 4.
− = Batch extraction value higher by ≃ factor of 3 to 4.
[1] Lower pH value is greater hydrogen ion concentration.

constituents on all columns showed evidence of rapid die off in concentration with time (volume) of leaching implying that simple equilibrium solubility was not the controlling factor. Otherwise, concentrations should be roughly those found for the batch extractions, which was not the case.

The disparity between batch and column values is of concern with regard to the field cell studies of Appendix E. The field cells have disposal media above and below the FBC waste material. What the disposal medium contributes alone is of importance in interpreting the field results and assessing the potential impact of the FBC waste disposal.

D.5 Waste Leaching with Disposal Media Step 1 Leachate

The Alliance AFBC waste was subjected to Step 1 and Step 2 leaching by leachate derived from Step 1 leaching of the shale and sandstone disposal media, respectively. The protocol was carried through seven repetitions of Step 2. Tables D-36 and D-37 present comparisons for the shale and sandstone media. Comparisons are drawn for the data from direct extraction of the wastes with deionized water (from the reproducibility study), disposal media extractions with deionized water (the Step 1 or reference values for the study extraction fluids) and the concentration after contact of the Alliance AFBC waste with Step 1 leachate from the disposal media.

These tables show that the waste contributed additional B, Ba, Ca, Cl, K, Mo, Na, OH, SO_4, Sr, TOC, and V to the extraction fluid beyond that originally contributed by the medium. As a consequence, specific conductance and total dissolved solids were also increased. Each medium contributed Mg, Mn, Si and total inorganic carbon to the deionized water. When this water is in turn brought into contact with the waste solids, decreases in TIC, Mn, and Mg occurred. The most probable mechanism is precipitation of magnesium as $Mg(OH)_2$ and manganese as one of several hydrous oxides. At high pH, manganous ion rapidly air oxidizes to Mn (III) and/or Mn (IV). Decreases in inorganic carbon most likely are due to precipitation of $CaCO_3$. While significant relative to TIC, the amount of calcium removed is small

TABLE D-36. COMPARISON OF STEP 1 LEACHATE CONCENTRATIONS FOR ALLIANCE AFBC WASTE AND SHALE DISPOSAL MEDIA[1]

Element/ Species	Leachate Concentrations		
	Waste with DI Water[2]	Disposal Medium with DI Water	Waste with Disposal Medium Leachate
Al	0.89	<0.25	0.32
B	0.28	0.062	1.1
Ba	0.42	0.12	0.86
Be	0.006	0.002	<0.002
Ca	1600	52	1600
Cd	<0.04	<0.04	<0.04
Cl	53	<2	57
Co	<0.03	<0.03	<0.03
Cr	0.032	0.019	<0.005
Cu	0.019	<0.005	<0.005
F	0.2	0.39	0.3
Fe	0.066	0.056	<0.040
K	57	4.7	57
Li	0.45	0.007	0.34
Mg	0.65	7.1	0.19
Mn	<0.005	0.13	<0.006
Mo	0.34	<0.01	0.36
Na	19	2.1	18
Ni	<0.015	0.071	<0.015
pH[3]	12	8	12
Si	<0.2	3.7	1.1
SO_4	1400	68	1320
Sp. Cond.[4]	7400	340	8950
Sr	22	0.13	21
TDS	3900	170	4500
Ti	<0.025	<0.025	<0.025
TIC	~3	24	2
TOC	4.7	2	3.8
V	0.12	<0.015	<0.015
Zn	<0.02	0.02	<0.015

[1] Concentrations in mg/L unless otherwise noted.

[2] Values from reproducibility study averages.

[3] Units are standard pH units.

[4] Units are micromhos/cm.

TABLE D-37. COMPARISON OF STEP 1 LEACHATE CONCENTRATIONS FOR ALLIANCE AFBC WASTE AND SANDSTONE DISPOSAL MEDIA[1]

Element/ Species	Leachate Concentrations		
	Waste with DI Water[2]	Disposal Medium with DI Water	Waste with Disposal Medium Leachate
Al	0.89	<0.25	<0.25
B	0.78	<0.045	0.7
Ba	0.42	0.056	0.72
Be	0.006	<0.002	<0.002
Ca	1600	73	1550
Cd	<0.04	<0.042	<0.04
Cl	53	<2	56
Co	<0.030	0.042	<0.03
Cr	0.032	0.018	0.005
Cu	0.019	0.005	<0.005
F	0.2	0.34	0.26
Fe	0.066	<0.04	<0.04
K	57	7.8	63
Li	0.45	0.035	0.37
Mg	0.65	22	0.19
Mn	<0.005	0.62	<0.006
Mo	0.34	<0.01	0.36
Na	19	1.6	18
Ni	<0.015	<0.015	<0.015
pH[3]	12.3	7.7	12.4
Si	<0.2	4.9	1.7
SO_4	1400	170	1440
Sp. Cond.[4]	7400	500	8950
Sr	22	0.18	22
TDS	3900	430	4530
Ti	<0.025	0.058	<0.025
TIC	~3	21	<2
TOC	4.7	0.7	1.7
V	0.12	0.21	<0.015
Zn	<0.02	<0.015	<0.015

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[1] Concentrations in mg/L unless otherwise noted.

[2] Values from reproducibility study averages.

[3] Units are standard pH units.

[4] Units are micromhos/cm.

compared to the total quantity present. Slight reduction is also observed for silicon after contact of the media leachates with the waste.

D.6 RCRA Extraction Results

Each of the three FBC wastes was subjected to the RCRA Extraction Procedure. The raw RCRA extraction data are contained in Appendix J. Table D-38 presents a comparison of the average values obtained with the RCRA limits for classification as hazardous. None of the waste extracts exceeded the RCRA standards. These results are not surprising in light of the experimental results obtained from the protocol Step 1 leaching experiments and the waste bulk solids content. These results also agree with other assessments of FBC solids (Reference D-14).

TABLE D-38. COMPARISON OF RCRA EXTRACTION PROCEDURE RESULTS WITH RCRA STANDARDS

		Exxon PFBC		Alliance AFBC		Georgetown AFBC	
Element	RCRA Limit (mg/L)	Avg. Value (mg/L)	Exceeds?	Avg. Value (mg/L)	Exceeds?	Avg. Value (mg/L)	Exceeds?
Ag	5.0	<0.05	No	<0.05	No	<0.05	No
As	5.0	<0.003	No	<0.003	No	<0.003	No
B	100.0	0.24	No	0.32	No	0.21	No
Cd	1.0	<0.05	No	<0.05	No	<0.05	No
Cr	5.0	<0.1	No	<0.1	No	<0.1	No
Hg	0.2	<0.001	No	<0.001	No	<0.001	No
Pb	5.0	<0.2	No	<0.2	No	<0.2	No
Se	1.0	<0.003	No	<0.003	No	<0.003	No

Table D-39 presents concentrations for all species in the solutions obtained by the Extraction Procedure and compares these values with data obtained by Step 1 extraction. Some species are present in higher concentration in the RCRA extract while others are not. The procedure and the final pH are quite different for the two methods and the "real world scenarios" being simulated are not the same. Even so, differences were seen among the wastes regarding which extraction procedure yielded the higher concentrations. Only barium, calcium and chloride were higher in the RCRA leachate for all three wastes. The differences in pH and/or ionic strength

TABLE D-39. COMPARISON OF RCRA EXTRACTION DATA WITH PROTOCOL STEP 1 LEACHATE CONCENTRATIONS[1]

Element/ Species	Exxon PFBC			Alliance AFBC			Georgetown AFBC		
	RCRA	Step 1	%Δ	RCRA	Step 1	%Δ	RCRA	Step 1	%Δ
Al	<0.05	0.8	–	1.7	1	-39	<0.05	0.17	–
As	<0.003	0.04	–	<0.003	–	–	<0.003	–	–
B	9.9	11	6.6	0.04	3.5	8750	<0.01	0.16	–
Ba	<1	0.2	–	<1	0.13	–	<1	0.19	–
Be	<0.001	NA[2]	–	<0.001	NA	–	<0.001	NA[2]	–
Ca	2650	1670	37	3940	1340	<-66	2600	1500	-42
Cd	<0.05	0	–	<0.05	0.04	–	<0.05	0.02	–
Cl	430	4.5	-99	374	51	<-8	390	24	-94
Co	<0.006	0.59	–	<0.006	0.08	–	<0.006	0.01	–
Cr	<0.1	0.09	–	<0.1	0.12	–	<0.1	0.05	–
Cu	<0.001	0.02	–	<0.001	0.14	–	<0.001	0.03	–
F	0.33	0.96	200	0.47	0.25	<-47	0.37	0.16	-57
Fe	<0.008	0.19	–	<0.008	0.08	–	<0.008	0.02	–
K	75	250	240	4.5	44	880	1.4	18	1170
Li	<0.001	–	–	<0.001	0.36	–	<0.001	0.50	–
Mg	420	1.4	-100	<0.030	0.81	–	0.072	2.7	3580
Mn	0.001	0	-100	<0.001	0.02	–	<0.001	0.01	–
Mo	0.095	2.5	2490	0.17	0.42	160	0.007	0.02	190
Na	4.7	17	270	1.8	13	640	0.66	6.6	890
Ni	<0.003	0.08	–	<0.003	0.11	–	<0.003	0.04	–
Pb	<0.2	0.03	–	<0.2	–	–	<0.2	–	–
pH[3]	9.9	12.0	21	12.3	12.4	1.1	12.3	12.5	2.0
Se	<0.003	0.06	–	<0.003	–	–	<0.003	–	–
Si	0.25	1.3	410	0.14	0.55	290	0.23	2.4	940
SO_4	1600	1200	-25	1350	1110	<-18	1030	1400	36
Sp. Cond.[4]	–	8130	7.4	–	8100	<-38	–	7780	-39
Sr	0.84	2.8	230	8.0	21	160	4.9	13	170
TDS[5]	–	3210	-71	–	3780	<-70	–	4000	-68
Ti	<0.005	0.05	–	<0.005	0.32	–	<0.005	0.06	–
TIC	–	–	–	–	–	–	–	4.3	–
TOC	–	1.3	–	–	1.2	–	–	3.9	–
V	0.31	0.09	-71	<0.003	0.26	–	<0.003	0.02	–
Zinc	0.08	0.13	63	<0.003	0.04	–	<0.003	0.01	–

[1] Concentrations in mg/L unless otherwise noted.

[2] NA = Not analyzed.

[3] Units are standard pH units.

[4] Units are micromhos/cm.

[5] Data for RCRA samples nor recorded because the Extraction Procedure requires addition of acetic acid to the samples.

can be invoked to explain the differences observed in most cases. The higher chloride in the RCRA samples may relate to high acetate values and subsequent interferences in the ion chromatograph analysis procedure.

D.7 FBC Leachate Attenuation/Mobilization by Disposal Media

Data resulting from contact of the Step 1 waste leachates with six different soils in protocol Steps 4, 5, and 6 are tabulated in Appendix J. Of concern is each disposal medium's ability to decrease (or increase) leachate concentations upon contact (attenuation or mobilization). The results of Steps 4, 5, and 6 are evaluated for each chemical species in terms of laboratory fractional attenuation, A_L, where:

$$A_L = \frac{C_i - C_f}{C_i}$$

where: C_i = initial concentration (before exposure to the disposal media)

C_f = final concentration (after exposure to the disopsal media)

Thus, a negative value for fractional attenuation represents a mobilization or enhancement of leachate concentration from the disposal medium. Positive values of A_L can be as high as 1.0 (when $C_f = 0$), but negative values have no such lower limit and can be very low when $C_f >> C_i$.

For Step 4 and each replication of Step 5, the initial concentration, C_i, is the Step 1 leachate concentration. For the Alliance AFBC and Georgetown AFBC wastes, the specific Step 1 leachates used in Steps 4 and 5 were analyzed individually. Each A_L was computed with the corresponding Step 1 value. For the Exxon PFBC waste (the first studied) the Step 1 leachates generated for the attenuation studies were not analyzed individually. Rather, the average values from the initial Step 1 replicates were presumed to be an adequate representation of all Step 1 leachates. In light of Step 1 data variability, this assumption was deemed somewhat tenuous. For this reason, specific analyses were conducted for each Step 1 leachate used in subsequent steps in the case of Alliance AFBC and Georgetown AFBC wastes. The attenuation data for the Exxon PFBC waste are considered less reliable for this reason.

Several phenomena can occur during exposure of the waste leachate to the disposal media. The most "desirable" would be reduction in constituent concentrations (including hydroxide ion, i.e., pH decrease). Ion exchange, some form of chemical or physical sorption, or even precipitation could effect reduction. The effect could be selective.

On the other hand, no reduction of concentration in the leachate constituent may occur, but simple mobilization from the soil may be experienced instead. This mobilization may be of the general magnitude which occurs by direct water leaching of the soils. Such change may or may not be seen depending upon the magnitude of the initial leachate concentration relative to the soil contribution and the variation in chemical analysis. In the latter situation, the behavior would be indistinguishable from no effect. Small positive or negative A_L values would be indicative of these cases. Replicates may reflect changes in sign of A_L.

Finally, significant increases in leachate concentration, greater than those attributable to simple water leaching of the disposal medium, could be the result of specific waste leachate action upon the soil. High pH dissolution or desorption might be expected. The high ionic strength of the waste leachate may lead to changes in ion exchange and sorption equilibria or simply increase solubility of soil components (the diverse ion effect).

The following paragraphs describe the primary (Step 4) and the secondary (Step 5 and Step 6) attenuation/mobilization for each species, for each waste, and for each disposal medium. The concentration trends and A_L values observed and the trends in A_L values with changes in volume-per-mass ratios are described. Appendix I presents additional anaysis of the observed concentration trends and advances possible chemical mechanisms to account for the behavior observed.

D.7.1 Protocol Step 4 Fractional Attenuation

Step 4 was performed using one-day, two-day, and seven-day extraction times. Table D-40 contains a summary of the protocol Step 4, seven-day fractional attenuation data for all chemical species, for each disposal medium, and for each of the three FBC wastes. When measured concentrations in the beginning (Step 1) leachate were at detection limits, fractional attenuation could not be evaluated. Missing entries reflect that situation. Most values reported are the mean of replicate experiments; however, in some instances only a single value could be computed. These situations are not flagged in the table but can be discerned from the raw data in Appendix J. When replicate values differed in sign, average values were not recorded, and the data were considered to be insignificant (if both positive and negative values were small in magnitude) or unreliable (if values were of opposite signs but of large magnitude). Analytical variabilities may be the cause in some cases and inherent variability in the materials in others.

Calcium values were attenuated (A_L = 0.3 to 0.8) by each medium for all three wastes. Sulfate was also attenuated in all combinations but with lower A_L values, 0.20 to 0.56. Total dissolved solids (TDS) tracked the behavior of Ca and SO_4, which is not surprising since TDS is composed principally of these two species.

Examination of the other constituents does not yield such uniformity of behavior. Consistency is not always seen for a particular species among the three wastes with a given medium or for a given waste with all six media. A brief comment on the behavior of each remaining leachate constituent for which A_L could be generated is given below.

Aluminum

A_L values were computed for Exxon PFBC and Alliance AFBC wastes. Behavior was not consistent for the Exxon PFBC waste leachate with all media. A_L is positive for the shale and interburden, mixed (one positive and one negative) for the sandstone, and negative for the other media.

TABLE D-40. SUMMARY OF LABORATORY FRACTIONAL ATTENUATION (A_L) VALUES FOR EACH OF THE WASTE AND DISPOSAL MEDIA COMBINATIONS

Element/ Species	Shale			Interburden			Sandstone			Glacial Till			Alluvium			Limestone		
	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC	Exxon PFBC	Alliance AFBC	Georgetown AFBC
Al	0.95	-0.18	–	0.56	0.62	–	#	0.82	–	-0.3	0.47	–	-0.6	0.74	–	-1.3	0.77	–
B	0.9	-1.1	–	0.97	0.77	–	0.97	0.6	–	0.94	0.97	–	0.96	0.88	–	0.96	0.97	–
Ba	#	0.73	0.24	0.71	0.84	0.37	#	0.96	0.26	#	0.9	0.32	-0.42	0.17	0.18	-0.3	0.68	0.42
Ca	0.85	0.67	0.6	0.25	0.55	0.65	0.53	0.46	0.54	0.66	0.67	0.61	0.67	0.58	0.54	0.66	0.50	0.47
Cl	–	#	0.59	-1.1	0.019	0.52	–	#	0.73	–	0.003	0.74	–	0.009	0.77	–	-0.057	0.65
Cr	0.95	0.38	–	#	0.72	–	0.34	0.43	–	-0.21	0.72	–	-0.47	0.54	–	-0.43	1	–
Cu	–	-1.6	–	–	0.61	–	–	0.26	–	–	-0.68	–	–	#	–	–	0.69	–
F	0.7	#	-0.18	-0.19	-7.1	-1	0.64	-0.44	-0.59	0.2	-0.36	-1.9	0.65	-4.6	-0.7	0.11	-1.5	-3.1
Fe	#	0.21	–	0.47	1	–	0.86	0.88	–	0.73	#	–	-0.91	-1.83	–	0.6	1	–
K	–	-0.027	0.03	–	0.029	0.03	–	-0.32	-0.28	–	0.44	0.57	–	0.15	0.31	–	-0.95	-1.1
Li	1	0.81	0.99	1	0.9	0.62	1	0.77	0.91	1	0.86	0.87	0.72	0.97	1	0.6	0.43	0.51
Mg	1	–	0.82	0.97	–	0.53	1	–	#	0.99	–	0.22	1	–	0.88	0.99	–	0.67
Mo	–	-0.32	–	–	-0.29	–	–	-0.12	–	–	-0.58	–	–	-0.037	–	–	-0.34	–
Na	–	-0.34	-0.31	-0.32	-0.31	-0.58	1	-0.24	-0.32	1	-0.35	-0.51	1	-0.03	-0.015	0.66	-1.4	-2.4
Ni	–	-0.39	-0.15	1	1	1	–	0.89	1	-30	1	-0.31	29	1	1	-38	1	0.36
Si	#	-3.5	-3.3	0.47	-1.5	-0.18	0.15	-0.73	0.091	-2.5	-6.74	-1.8	-0.66	-1.7	-0.18	-0.71	-1.3	0.12
SO_4	0.41	0.54	0.32	0.04	0.45	0.17	0.2	0.34	0.16	0.23	0.47	0.24	0.4	0.56	0.36	0.39	0.44	0.29
Sp.Cond.	–	–	0.68	–	–	0.56	–	–	0.48	–	–	0.67	–	–	0.57	–	–	0.45
Sr	0.5	0.31	0.34	#	0.26	0.29	0.18	0.064	0.19	0.61	0.48	0.54	0.34	0.17	0.31	-0.14	-0.067	0.077
TDS	0.6	0.6	0.64	0.36	0.4	0.41	0.33	0.5	0.58	0.48	0.63	0.51	0.67	0.55	0.62	0.44	0.5	0.56
Ti	–	-0.85	–	–	0.52	–	–	0.36	–	–	0.66	–	–	0.65	–	–	0.63	–
TIC	–	–	1	–	–	1	–	–	0.83	–	–	1	–	–	1	–	–	1
TOC	–	–	-1.2	-3	–	-0.7	–	–	-0.35	–	–	-2	–	–	-0.99	-1.4	–	-0.54
V	–	-1.4	–	–	0.4	–	–	#	–	–	0.47	–	–	0.54	–	–	0.48	–
Zn	#	-0.52	–	#	1	–	0.95	0.75	–	0.92	1	–	0.91	1	–	0.86	1	–

NOTE: Most values are the mean of duplicate pairs. Missing values indicate that the Step 1 concentration was at the detection limit.
= 1 positive and 1 negative, so average value is not reported.

In contrast, A_L for the shale is negative for the Alliance AFBC waste leachate and strongly positive for all other media. Initial aluminum concentrations for the two wastes are similar and soil contributions were below detection limits for all six media.

Boron

A_L values were obtained for the Exxon PFBC and Alliance AFBC wastes. The values are high positive for all media for both wastes except the Alliance AFBC leachate with shale.

Barium

A_L values were obtained for all three wastes. Values for Exxon PFBC are mixed (one positive and one negative) for all media except alluvium and limestone, which have negative values. A_L values for the Alliance AFBC leachate are all positive and large. A_L values for the Georgetown AFBC leachate are consistently positive but considerably smaller in magnitude than for the Alliance AFBC leachate. Initial barium concentrations were not appreciably different for the three wastes. Soil leaching values were a significant proportion of the mean values reported for the waste leachates; they were nearly equal for the shale, glacial till and limestone media.

Chromium

A_L values were computed for the Exxon PFBC and Alliance AFBC wastes. The Exxon PFBC values are mostly negative or mixed except for the shale and sandstone media. Alliance AFBC values are all positive and greater than 0.35. Values for the two waste leachates are similar only for the sandstone medium. The interburden yielded high leachate chromium values.

Copper

A_L values were computed only for the Alliance AFBC wastes. Values vary widely from positive to negative depending upon the medium. Medium leachate values were all low except for the interburden, where the 0.088 mg/L value was ~60 percent of the mean waste leachate value. A_L for the interburden is 0.61, however.

Iron

A_L values were computed for the Exxon PFBC and Alliance AFBC wastes. Shale and alluvium A_L values are mixed for the Exxon PFBC waste but low positive (0.21) and strong negative (-1.83) for the Alliance waste. All other Exxon values are high positive. The Alliance values are in close accord for all but the glacial till. Soil leachate values were low for all but the interburden (0.24 mg/L).

Potassium

A_L values were obtained for the Alliance AFBC and Georgetown AFBC wastes. Values for both leachates are similar, low and variable (positive and negative) for shale and interburden, moderately negative for sandstone, more strongly negative for limestone, and positive for glacial till and alluvium. All media except glacial till and alluvium contributed 4 to 8 mg/L of potassium to deionized water during leaching.

Lithium

A_L values were obtained for the Alliance AFBC and Georgetown AFBC wastes. Consistently high attenuations were found for both waste leachates, (A_L = 0.6 to 1.0) except for limestone (where A_L = 0.43 and 0.51).

Magnesium

A_L values were computed for the Georgetown AFBC waste only. Leachate concentrations were too low for other wastes. A_L values are all positive except for sandstone, where mixed values were obtained. The range of positive A_L values is 0.22 to 0.88. Sandstone had the highest medium leachate magnesium value (22 mg/L).

Molybdenum

A_L values were obtained for the Alliance AFBC waste only. All values were negative (A_L = −0.04 to −0.50) even though media leachates were all at or near detection limit except for the limestone leachate. Mobilization by basic solution is possible.

Sodium

A_L values were obtained for all three wastes. Values are generally positive for the Exxon PFBC waste except for the interburden. But all values are negative for the other two wastes. The most negative A_L values were found for the limestone medium for both AFBC waste leachates. The limestone Step 4 leachate had the highest sodium content, 22 mg/L.

Nickel

A_L values were computed for the Alliance AFBC and Georgetown AFBC wastes. Positive values are seen for both wastes for interburden, sandstone, alluvium, and limestone. Both wastes have negative values for shale while the Alliance value is 1.0 for glacial till; the Georgetown value is 0.31. Of the media leachates, the interburden had the greatest nickel concentration at 0.26 mg/L, and the shale leachate was second at 0.07 mg/L.

Silicon

A_L values were computed for all three wastes. A_L values are variable in magnitude but are typically negative. The two positive values are small (Georgetown with sandstone, 0.09, and with limestone, 0.12). Media leachate silicon concentrations were generally higher to much higher than the Step 1 waste leachates.

Strontium

A_L values were obtained for all three wastes. Except for the interburden, where a negative value (A_L = -0.2) was obtained for the Exxon PFBC waste (vs 0.26 and 0.29 for the other two), all other A_L values are similar for the three wastes with each of the media. All are positive (lower values for the sandstone) except for the limestone, whose values are very low and are mixed positive and negative. Waste leachate concentrations were 1 to 2 orders of magnitude greater than the soil leachates.

Titanium

A_L values were obtained for the Alliance AFBC waste only. The values are consistently high positive (0.36 to 0.65) except for the shale medium, which is just the opposite at -0.85. Media leachate values were uniformly low at <0.025 to 0.05 mg/L. The initial waste leachate was constant for all media at 0.071 mg/L (average of two).

Vanadium

A_L values were computed for the Alliance AFBC waste only. Shale and sandstone values (negative and mixed, respectively) differ from the other four media which are uniformly positive and range from 0.40 to 0.54. Soil leachate values were uniformly at or near the detection limits.

Zinc

A_L values were obtained for the Exxon PFBC and Alliance AFBC wastes. Values are all high positive for both wastes for sandstone, glacial till, alluvium, and limestone. Behavior for the shales values is mixed for the Exxon leachate and negative for the Alliance leachate. For the interburden, a negative value was obtained for the Exxon leachate (A_L = -0.5) but complete attenuation was obtained for the Alliance leachate (A_L = 1.00).

Chloride

A_L values were computed for the Alliance AFBC and Georgetown AFBC wastes. Variable values (mixed, low positive, low negative) for the Alliance leachate imply little or no attentuation. The opposite is seen with the Georgetown leachate; all values are large and positive. Media contributions were low. Initial chloride values for the Alliance leachate were 53 mg/L but only 23 mg/L for the Georgetown leachate.

Fluoride

A_L values were computed for all three wastes. Behavior for the Exxon leachate differs from that of the other two. A_L values (except for the interburden) are positive and reflect moderate to strong reduction. A_L values for the Alliance leachate range from mixed to low negative to high negative. The Georgetown values are uniformly negative and occasionally large. The large values for the Alliance and Georgetown leachates are not coincident, however. Soil Step 1 leachate values range the same as values for the wastes (0.13 to 1.0). The Exxon leachate with the highest value shows attenuation, whereas the other waste leachates show mobilization. Some relationship is indicated between the A_L and soil Step 1 leachate for the two AFBC waste leachates.

What evolves from the above examination is the absence of clearly consistent attentuation/mobilization behavior from the Step 4 data. Some instances of a consistency between wastes and/or between media for a given waste are indicated. However, as many contradictions as similarities are present.

D.7.2 Comparison of Step 4 Fractional Attenuation Values for One-, Two-, and Seven-Day Contact Times

For all fractional attenuation studies, the Step 1 leachate used in Step 4 was generated by seven-day leaching. This leachate was then contacted with the individual soils for periods of one, two, and seven days. Thus only the A_L component is time variable, not the initial leaching process.

As noted, for the Exxon PFBC waste, the exact values for Step 1 concentrations were not known for each individual aliquot used in Step 4. Average values for Step 1 leachates were used as the initial value. For the Alliance AFBC waste, exact matching of Step 1 and Step 4 concentrations were used in the A_L computations because each of the Step 1 leachates generated in this part of the study were analyzed.

Tables D-41 and D-42 contain tabulation of the average (of two replicates) A_L values for each medium, for each species, and for Step 4 contact times of one, two, and seven days, respectively, for the Exxon PFBC waste and the Alliance AFBC waste.

The primary criterion for an effect of contact time would be a consistent trend of increasing or decreasing A_L with increasing contact time. No change with time would be a clear indication of no time dependence beyond the first day of contact. The presence of any other type of dependence such as increase followed by decrease, or vice versa, would be hard to verify with only three data points.

Examination of Tables D-41 and D-42 leads to the summary of Table D-43. Only those elements where a trend for A_L was indicated for at least one waste and for at least one disposal medium are included. Meaningfulness of

TABLE D-41. STEP 4 LABORATORY ATTENUATION (A_L) VALUES FOR ONE-, TWO-, AND SEVEN-DAY CONTACT TIME FOR EXXON PFBC WASTE LEACHATES

Element/ Species	Shale			Interburden			Sandstone			Glacial Till			Alluvium			Limestone		
	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days
Al	0.5	-0.25	0.8	0.4	-1.1	0.5	0.4	-1.5	#	-2.2	-0.77	-0.3	-1.9	-0.91	-0.5	-2.3	-0.9	-1.5
B	0.99	0.94	0.9	0.67	0.75	0.9	0.79	0.82	0.9	0.78	0.77	0.95	0.75	0.83	1	0.84	0.86	1
Ba	0.47	-0.57		0.52	0.36	0.7	0.58	-0.23	#	0.33	-0.49	-	-1	-0.95	-0.4	-0.37	-0.5	-0.3
Ca	0.16	0.56	0.8	-0.13	0.5	0.3	-0.15	0.44	0.55	0.57	0.57	0.65	0.51	0.55	0.7	0.53	0.52	0.7
Cl	#	-		0.17	-		#	-	-	-	-	-	-		-	-	-	-
Cr	#	0.2	1	1	#		0.81	#	0.4	-0.99	-0.14	0	-0.87	-0.39	-0.5	-1	-0.19	-0.5
F	0.52	0.74	0.8	-0.089	0.22		0.36	0.054	0.6	-0.017	0.16	0.25	0.31	0.36	0.6	0.18	-0.082	0.2
Fe	-0.5	0.58		0.22	0.6		#	0.36	0.8	0.23	0.5	0.5	0.099	0.35	#	0.34	0.62	0.5
K	#	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-
Mg	0.95	0.98		0.96	0.99		0.96	0.99	-	0.94	0.95	-	0.99	0.99	-	0.87	0.96	-
Mn	#	-7.5		1	-11		1	-16	-	-19	-9.3	-	-23	-16	-	-21	-9.9	-
Na	#	0.56	0.2	0.82	0.29	-0.3	0.86	0.17	-	#	0.43	1	0.12	0.39	0.5	-0.18	0.18	0.6
Ni	#	-15		1	-22		1	-27	-	-30	-17	-	-28	-20	-	-31	-20	-
Si	-0.96	-4.1		-0.84	-3.5	-0.5	-0.7	-2.9	0	-8.4	-7.2	-2.5	-4.6	-2.9	-0.7	-2.1	-1.9	-0.7
SO_4	0.23	0.44	0.4	-0.027	-0.011	0.29	0.038	0.042	0.2	0.066	0.12	0.26	0.15	0.22	0.45	0.21	0.21	0.4
Sr	-0.39	0.036	0.5	-0.77	-0.032	-0.2	-0.74	#	0.2	0.39	0.32	0.6	0.22	0.17	0.45	-0.27	-0.6	#
TDS	0.5	0.38		0.25	0.26	0.4	0.22	0.19	0.3	0.31	0.37	0.5	0.23	0.34	0.65	0.23	0.3	0.5
Zn	#	1		-0.83	1	-0.5	0.57	0.98	0.9	0.93	1	0.9	0.94	1	0.9	0.9	1	0.7

= Value not recorded, 1 value positive and 1 value negative found for A_L.

TABLE D-42. STEP 4 LABORATORY ATTENUATION (A_L) VALUES FOR ONE-, TWO-, AND SEVEN-DAY CONTACT TIME FOR ALLIANCE PFBC WASTE LEACHATES

Element/ Species	Shale			Interburden			Sandstone			Glacial Till			Alluvium			Limestone		
	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days	1 day	2 days	7 days
Al	0.82	0.84	-0.18	0.83	0.68	0.62	0.48	0.62	0.82	0.74	0.79	0.47	0.72	0.86	0.74	0.88	0.83	0.77
B	0.76	0.79	-1.1	0.7	0.53	0.77	0.3	0.48	0.6	0.71	0.74	0.97	0.79	0.89	0.88	0.79	0.96	0.97
Ba	0.25	0.29	0.73	0.48	0.55	0.84	0.69	0.65	0.96	0.27	0.46	0.9	-1.2	-1.1	0.17	0.37	0.20	0.68
Be	0.83	1	-	0.75	0.58	-	0.42	0.58	-	0.83	0.75	-	1	1	-	1	1	-
Ca	0.39	0.45	0.67	0.34	0.37	0.55	0.22	0.28	0.46	0.43	0.5	0.67	0.33	0.41	0.58	0.42	0.42	0.5
Cd	1	1	-	1	1	-	0.56	1	-	1	1	-	1	1	-	1	1	-
Cl	0	0.98	#	0	0.13	0.019	0.049	0.029	#	0.039	0.029	0.003	0.049	0.02	0.009	0	0.02	-0.057
Co	0.81	1	-	0.85	0.62	-	0.34	0.4	-	0.87	0.74	-	0.83	1	-	0.74	1	-
Cr	0.6	0.68	0.38	0.61	0.51	0.72	0.23	0.42	0.43	0.62	0.66	0.72	0.62	0.76	0.54	0.65	0.82	1
Cu	0.64	0.71	-1.2	0.69	0.56	0.61	0.22	0.35	0.26	0.32	0.28	-0.68	0.43	0.59	#	0.73	0.87	0.69
F	-0.22	0.13	#	-1.1	-1	-7.1	-0.39	-0.13	-0.44	-0.8	-1.6	-0.36	-0.69	-0.1	-4.6	-1.5	-1.7	-1.5
Fe	0.88	0.9	0.21	1	0.92	1	0.77	0.78	0.88	0.85	0.82	#	0.41	0.41	-1.8	0.88	0.62	1
K	-0.01	#	-0.02	-0.015	-0.02	0.03	-0.071	-0.12	-0.32	0.35	0.4	0.44	0.16	0.11	0.15	-0.69	-0.77	-0.45
Li	0.82	0.87	0.81	0.83	0.84	0.9	0.63	0.69	0.77	0.76	0.79	0.86	0.91	0.95	0.97	0.46	0.46	0.43
Mg	0.59	0.67	-	0.62	0.53	-	0.29	0.4	-	0.63	0.63	-	0.62	0.75	-	0.62	0.68	-
Mn	0.67	0.8	-	0.74	0.71	-	0.56	#	-	0.8	0.55	-	0.64	#	-	0.77	0.73	-
Mo	-0.073	-0.1	-0.32	-0.19	-0.26	-0.29	-0.054	0.073	-0.12	-0.46	-0.48	-0.58	#	-0.014	-0.04	-0.3	-0.35	-0.34
Na	-0.11	-0.14	-0.34	-0.29	-0.32	-0.31	-0.087	-0.15	-0.24	-0.56	-2.7	-0.35	0.037	0.027	-0.03	-1.1	-1.2	-1.4
Ni	0.39	0.98	-0.39	0.46	0.32	1	0.2	0.34	0.89	0.47	0.39	1	0.73	1	1	0.46	1	1
Si	-1.6	-1.1	-3.5	-0.89	-0.76	-1.5	-0.34	-0.57	-0.73	-2.6	-2.6	-6.7	-0.9	-0.35	-1.7	#	#	-1.3
SO_4	0.26	0.39	0.54	0.12	0.2	0.4	0.044	0.18	0.34	0.24	0.32	0.47	0.31	0.41	0.56	0.43	0.47	0.44
Sr	0.13	0.16	0.31	0.17	0.17	0.26	0.073	0.058	0.06	0.33	0.37	0.48	0.11	0.13	0.45	-0.011	-0.06	-0.07
Ti	0.69	0.75	-0.85	0.7	0.57	0.52	0.31	0.44	0.36	0.7	0.72	0.66	0.68	0.87	0.65	0.71	0.87	0.63
TDS	0.35	0.44	0.6	0.38	0.35	0.45	0.13	0.2	0.5	0.41	0.46	0.63	0.34	0.42	0.55	0.41	0.41	0.5
V	0.54	0.51	-1.4	0.51	0.37	0.4	0.26	0.3	#	0.51	0.59	0.47	0.39	0.75	0.54	0.46	0.68	0.48
Zn	0.82	1	-0.52	1	0.6	1	0.27	0.46	0.75	1	0.68	1	1	1	1	1	1	1

- Value not recorded, 1 positive value and 1 negative value found for A_L.

TABLE D-43. SUMMARY OF TIME DEPENDENT TRENDS OF A_L VALUES BY WASTE AND BY DISPOSAL MEDIUM

Element/ Species	Shale		Interburden		Sandstone		Glacial Till		Alluvium		Limestone	
	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC
Al				Decrease		Increase						Increase
B	Sl. Decrease		Increase		Increase	Increase	Increase	Increase	Increase	~Increase	Increase	Increase
Ba		Increase		Increase		~Increase		Increase		Increase[1]		~Increase
Ca	Increase	Increase	~Increase	Increase	Increase	Increase	~Increase	Increase	Increase	Increase	Increase	Increase
Cr	Increase				Increase[1]	Increase		Increase				Increase
Cu								Decrease[1]				
F	Increase						Increase		Increase			
Fe	(Increase)[2]		(Increase)		Increase	Increase	Increase					
K						Decrease[1]		Increase				
Li			Increase			Increase		Increase		Increase		
Mo		Decrease[1]		Decrease[1]		Decrease[1]		Decrease[1]		Decrease[1]		~Decrease[1]
Na		Decrease[1]	Decrease	~Decrease[1]		Decrease[1]	Increase		Increase	Decrease[1]	Increase	Decrease[1]
Ni						Increase						
Si		~Decrease[1]		~Decrease[1]		Decrease[1]		~Decrease[1]		~Decrease[1]		~Decrease[1]
SO_4	Increase	Increase	Increase[1]	Increase	Increase	Increase	Increase	Increase	Increase	Increase	Increase	
Sr	Increase	Increase		Increase	Increase		~Increase	Increase	~Increase	Increase		Decrease[1]
TDS		Increase	Increase	~Increase	Increase	Increase	Increase	Increase	Increase	Increase	Increase	Increase
Ti				Decrease								

[1] One or more negative A_L values in trend.

[2] ( ) Indicates only 2 values were recorded.

this trend relative to individual variations in the data pairs or composite variance for data pairs making up the set has not been tested statistically. In some cases, the approximate sign (~) was used to indicate that the two-day value may have varied slightly in the opposite direction relative to the one-day value but that seven-day was clearly greater (or less) than the one-day/two-day value pair.

For many species, wide variations were seen among the one-day, two-day, and seven-day sets where oscillation between positive and negative A_L values was exhibited. Such behavior may also be related to the time of contact but minor analytical variations could also yield such oscillations when the absolute values involved in computing A_L are small and in the region of analytical detection limits. These species are not recorded in Table D-43.

Of those species represented in Table D-43, some are not consistent in behavior for different media for a particular waste and some are not consistent for both wastes for a particular medium. In part this is because A_L values were not calculated (could not be calculated) for some species for the Exxon PFBC waste. However, in some cases, a trend was seen for one waste and not the other.

The net evaluation of Tables D-41, D-42, and the resultant summary, Table D-43, is that some dependency on time of contact is indicated for the A_L value obtained. Most notable are the major species (calcium and sulfate) and a direct result of their combined values, total dissolved solids (TDS). Strontium and boron generally yield increasing A_L values with increased contact time. For the Alliance AFBC waste leachate, A_L for silicon consistently declined to more negative values as did the sodium A_L for the same waste. On the other hand, the sodium A_L values increased for three soils with the Exxon PFBC leachate. Of the other species represented in Table D-43, only barium A_L changes were consistent for all soils and this was only for the Alliance AFBC waste.

The conclusion to be drawn from these data is that some time-of-exposure dependence is indicated for Step 4, which is different from the case for Steps 1, 2, and 3 for the protocol.

D.7.3 Protocol Step 5 Fractional Attenuation (Exxon PFBC and Alliance AFBC Wastes Only)

Replication of Step 5 attenuation, which involves exposing the same sample of disposal medium to fresh leachate with each replication of the step, would be expected to develop a pattern of attenuation or mobilization if a consistent physical or chemical mechanism were operative and following simple behavior. Sorption or ion exchange control would demonstrate a geometrically declining A_L as a function of repetition (increasing VPM). Mobilization, on the other hand, could be complete upon first contact (Step 4) or later with subsequent addition of leachate resulting in attenuation.

Step 5 was performed on the Exxon PFBC and Alliance AFBC waste leachates. Computer plots of A_L as a function of Step 5 repetition (increasing VPM) were generated and examined. A summary of the observed attenuation/mobilization behavior is shown in Table D-44. Representative plots showing the various types of behavior are presented in Figures D-36 to D-47 (see Attachment 2) in the range above VPM = 10.

For some species, a pattern is seen that is consistent across the range of disposal media and to a lesser extent, between the two wastes. Typically calcium and sulfate show a steady decline in A_L with increasing VPM. However, in many instances the decline is not smooth and considerable scatter is seen in the A_L plots. TDS tracks well with the calcium and sulfate data as would be expected. Many species showed a continued decline in A_L to negative values implying desorption or redissolution of material previously removed in earlier steps. For other species, increases in A_L were seen with successive steps, but generally these increases were from more negative A_L values to less negative values.

TABLE D-44. SUMMARY OF PROTOCOL STEP 5 FRACTIONAL ATTENUATION (A_L) BEHAVIOR WITH INCREASING VOLUME-PER-MASS RATIO FOR EXXON PFBC AND ALLIANCE AFBC WASTE LEACHATES

Element/ Species	Shale		Interburden		Sandstone		Glacial Till		Alluvium		Limestone	
	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC
Al	D→ –(E)	(E)	D→ –(E)	D(E)	D→ –(E)	D→ –(E)	(E)	D→ –(E)	(E)→ –	(E)(I)	(E)→ –	D(E)
B	Const	I(E)→ +	D	D→ –(E)	Const	D→ –(E)	D(C)	D→ –(E)	D	D(E)	D(+)	D(E)
Ba	D→ –(E)	D→ –(E)	D→ –(E)	D(E)	D→ –(E)	D→ I(E)	D→ (E)	D→ –(E)	(E)(±)	D→ –(E)	I→ D(E)	D(E)
Ca	D(C)	D(E)	D	D(E)	D	D(E)	D(C)	D(E)	D(E)	D(E)	D(E)	D(E)
Cr	D(E)	(E)	D→ –(E)	D(E)	D→ –(E)	(E)	D→ –	D→ –(E)	D→ –(E)	D→ –(E)	(E)(–)	D→ –(E)
F	D	D→ –(E)	I→ Const	I→ 0	Const (+)	(E)(+)	I→ Const	(E)(–)	D(C)	I(–)	D(E)	(E)(–)
Fe	Const (+)	(E)	Const (+)	E(+)	Const (+)	D→ –(E)	D(+)	(E)	(E)(–)	(E)(–)	(E)(+)	D→ –(E)
Na	Const (+)	I(–)	D	I→ +(E)	(E)(+)	I→ +	D→ –	I→ +	(E)(+)	D→ I	(E)(–)	D–I(–)
Si	(E)	I→ +	(E)±	I→ +	(E)(+)	(E)(±)	(E)	I→ +	(E)(–)	I→ +	E(–)	I(–)
SO_4	D(C)	D(C)	I→ 0	D(E)	D(C)	D	D(C)	D(C)	D(C)	I→ D(+)	D→ –(E)	D→ –(E)
Sr	D→ I	(E)	D→ I	D→ –E	(E)(+)	D→ I(E)	D	D(E)	(E)(+)	D→ I(E)	E(+)	I→ +
TDS	D(C)	D(C)	D(C)	D→ I	D→ –	D	D(C)	D(C)	D→ –(E)	D	D→ –(E)	D(C)
Zn	Const (+)	I→ +(E)	0→ I	Const→ 0	Const (+)	D→ –(E)	D	D(E)	D(+)	D→ –(E)	(E)	D→ I

D = Decrease
I = Increase
Const = Constant
(E) = Erratic
(C) = Consistent
+ = Positive values
– = Negative values
– = Change to
0 = A_L value at zero

D.7.4 Protocol Step 6 Fractional Attenuation

Step 6 attenuation studies were performed on the Exxon PFBC and the Alliance AFBC wastes. Repeated contact of the same leachate sample with fresh soil (the protocol Step 4, Step 6 repetition sequence) would also be expected to develop a pattern of attenuation or mobilization if a simple physical or chemical mechanism were operative. In the absence of any contribution from the soil matrix, simple ion exchange or sorption behavior would be expected to result in positive A_L values with repeated replacement of the matrix. Negative A_L values can only be the result of mobilization from the soil matrix. (An exception is single case situations where large single analysis variation can result in higher numbers after contact than before.)

Large positive A_L values for Step 4 might well be followed by small positive or small negative A_L values as the attenuation capacity of the medium is "exhausted." When the medium releases substantial quantities of a constituent to the leachate upon contact, then A_L should be negative and numerically large for Step 4 but remain relatively constant or become less negative upon repetition of Step 6. The presumption here is that the change in concentration would be relatively independent of the repetition step but the absolute value of concentration should increase with successive steps.

Table D-45 presents a summary of A_L behavior for the Exxon PFBC and Alliance AFBC wastes. Representative plots showing fractional attenuation (A_L) behavior in Steps 4 and 6 are presented in Figures D-36 to D-47 (at VPM values of less than 10). Step 6 replicates correspond to values of VPM less than 10. (Step 4 is VPM = 10.) Table D-45 shows that for several species, the A_L values are erratic, many times becoming negative, indicating increases in concentration upon successive soil additions. For other species, more consistent patterns are seen.

The fractional attenuation values should reflect the species concentration behavior on successive contacts with fresh soil, but the erratic variation in A_L tends to obscure the concentration trends. Examination of

TABLE D-45. SUMMARY OF PROTOCOL STEP 5 FRACTIONAL ATTENUATION (A_L) BEHAVIOR WITH INCREASING VOLUME PER MASS RATIO FOR EXXON PFBC AND ALLIANCE AFBC WASTE LEACHATES

Element/ Species	Shale		Interburden		Sandstone		Glacial Till		Alluvium		Limestone	
	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC
Al	E	E	L⊕$_\Delta$ –E	E, ⊖	E, ⊖ $_\Delta$⊕$_\Delta$⊖	L⊕ → M⊖↓	E	L⊕ → ⊖ E	E	E	L⊖↑	L + → L – (E)
B	E⊕ → S⊖	L⊖ → S⊕↑	L+$_\Delta$ M–	M⊕ → ⊖ E	L⊕ → M⊖↓	M⊕ → M⊖↓	L⊕ → S⊕↓	L⊕↓(E)	L⊕ → ⊖↓	L⊕ –C(E)	L⊕↓L⊖	L + → L⊖↓
Ba	E, → L⊖	L⊕ → 1⊖↓	E, + –	E, M⊖$_\Delta$ L⊕	E, ⊕ → ⊖$_\Delta$⊕	L⊕ → L⊖⊕	L⊕ → ⊖ E	⊕$_\Delta$⊖ E	M⊖ → S ±↑	⊖ → ⊕	0 → ⊕⊖ E	
Ca	L⊕ → S⊕⊖	M⊕ → S⊖$_v$	M⊕↷→L⊖	M + → S⊖↓	M⊕ → S⊖↓	M⊕ → S⊖↓	L⊕ → 0↓	M⊕ → 0↓	L⊕ → S⊕↓	M⊕ → 0↓	L⊕ → S⊕↓	M + → 0(E)
Cr	E +, –	E +, –	E +, –	E	E⊕ → ⊖↷	M⊕ → M⊖ (E)	E⊕ → ⊖	L⊕ → S⊖ E	E	L⊕↓(E)	E⊖$_\Delta$⊕	L⊕ → S⊕ E
F	L + → S +↓	–	M⊕$_\Delta$+,–	–	L⊕ → S⊖, ⊕	–	S⊕↓	–	L⊕↓(E)	–	S⊕ → S⊖	–
Fe	E – → +↓	E	E → L⊖↗	E, 0 → L⊖	E – → +	L⊕ → ⊖, E	E	E	E L –$_\Delta$ $^{M}_{S}$+	E	Ⓔ⊕ → ⊖	ⒺL⊕ → M⊖
Mn	S + → S –	S⊖ → S⊕	E	S⊖↗	E, S⊕ → S⊕	S⊖↑ 0	E⊖	⊖$_m$↕ S	S⊕ → S⊖	⊖	M⊕↑↓⊖	L⊖$_\Delta$S⊖↑
Si	L⊖ → S –, S +	L⊖ → S⊖	S – → L –	L⊖ → S⊖↑	E – → +	E⊖	L⊖ → S⊖	S⊖ → 0↑	L⊖ → S⊖↑	⊖ E	M⊖↓L⊖↑S⊖	E⊖
SO_4	L + → S⊖ (C)	M⊕ → S⊖	S⊕ → S 0	S⊕ → S⊖↓	S⊕ → S⊖↓	S⊕ → S⊖↓	S⊕ → S⊖↓	M⊕$_\Delta$S⊖	M⊕ → 0↓	M⊕$_\Delta$0↓	M⊕ → S⊖↓	M + → $^{S⊕}_{S⊖}$↓
Sr	L + → S⊖↓	~S⊕ ~C	~0 ⊕↝L⊖	M⊕$_\Delta$S⊕↓	M⊕ → S⊖	S⊕↑	L⊕$_\Delta$S⊕↓	S⊕ → M⊕↑	M⊕ → S⊕↓	S⊕↑	E	S⊖ → M⊕↑
TDS	L + → S –(E)	M⊕ → S⊖↓	M⊕ → S⊖	M⊕ → S⊖	M⊕ → M⊖	M⊕$_\Delta$M⊖↓	M⊕ → ⊖	M⊕$_\Delta$S⊖	L⊕↓S$^{⊕}_{⊖}$	M⊕ → S⊖↓	M⊕ → S⊖↓	M⊕ → S⊖$_v$
Zn	L⊕ → E⊕⊖	M⊖ → S⊕	0 → L⊖ → S⊖	E	E⊕$_\Delta$⊖$_\Delta$⊕	M⊕ → M⊖↓	L⊕ → S⊖↓	L⊕ → S⊖↓	L⊕$_\Delta$L⊖	L⊕ → L⊖Ⓔ	E – L⊕ → L⊖	–

L – Large (0.7 or greater)
M – Medium (0.04 – 0.71)
S – Small (≲0.4)
E – Erratic

L⊖ → S⊕ or not decrease in A_L in general indicates media contribution becoming significant.

concentration rather than A_L versus VPM plots for VPM ≤ 10 provides a somewhat clearer picture of the attenuation behavior. Table D-46 summarizes the concentration behavior for the Exxon PFBC and Alliance AFBC wastes for Step 6 replicates for VPM values of less than five. Some consistent behavior is seen. For all combinations of waste and media, pH show a continuing decline as VPM decreased. For all systems, manganese increased as VPM decreased. Other species generally showing significant increases in concentration were sulfate, silicon, and sodium. Other species failed to show consistent patterns of increase for all media and both wastes. Potassium was the only species that essentially remained constant under all conditions. Molybdenum (with one exception) showed a consistent decline with increasing VPM. Wastespecific or medium-specific patterns are difficult to discern. Calcium concentrations did remain constant or increase for both wastes in contact with shale, interburden, and sandstone but decreased for both wastes with glacial till, alluvium, and limestone.

The much lower pH developed from the interburden medium did elevate some of the heavy metals over concentrations observed for other media.

D.7.5 Protocol Step 7 Burdened Disposal Media Leaching

D.7.5.1 Step 7 Repetitions

Stp 7 data for the leaching of four disposal media (shale, interburden, sandstone, and the original [Greer] limestone) with deionized water after contact with the Exxon PFBC Step 1 leachate are contained in Appendix J. The data were examined for trends in resultant concentrations upon repetition of Step 7. Table D-47 summarizes these results and also tabulates the single sample maximum concentration value observed for each species for the four media.

Consistently, the solution pH was moderately to strongly basic in the first Step 7 sample for each medium. Successive repetitions decreased pH but never below neutrality (pH = 7). Slightly alkaline values always resulted. Most likely, this phenomenon was the result of dilution of the

TABLE D-46. SUMMARY OF CONCENTRATION BEHAVIOR FOR PROTOCOL STEP 6 REPETITIONS (VPM LESS THAN FIVE) FOR EXXON PFBC AND ALLIANCE AFBC WASTES

Element/ Species	Shale		Interburden		Sandstone		Glacial Till		Alluvium		Limestone	
	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC	Exxon PFBC	Alliance AFBC
Al	SD	~C(V)	I	I	(N)I(V)	I	(N)I	SI	C(V)	~C(V)	~C(V)	~C(V)
B	SD	~C(V)	(N)SI	(N)D	(N)I(V)	I	D	D-0	SI(V)	~C(V)	(N)SI(V)	(N)SI(V)
Ba	SI	(V)	(N)C	D	~C	V	(N)SI	~C(V)	~C(V)	(N)D(V)	~C(V)	~C(V)
Ca	SI	I	~C	SI	~C	I	D	D	D	D	SD	D
Cd	C	SD	(N)D	I	0	SI	0	0	0	0	(~0)~C	0
Cl	0	V	SI	(V)I	0	V	0	D	0	~C	0	I
Co	SD	SI(V)	(N)C(V)	I	0	SI	0	D-0	0	SI	(~0)~C	0
Cr	SD	SI(V)	(N)C(V)	(N)D(V)	~C(V)	SI	SD	SD	D to 0	SD	~C	D-0
Cu	SD	SI(V)	I	I	SD(N)	SI(N)	SD	SD	D to 0	SD	~C	0
F	D	SD	(V)	~C(V)	(N)SI(V)	SI(N)	D	D	D	~C(V)	I	I
Fe	D	SI(V)	I	I	SD(N)	(N)SI(V)	SI(V)	SD	D	SD(V)	SI(V)	~C
K	C	C	C	C	C	C	C	C	C	C	C	C
Li	D	D	0	I	I	SI	SI(V)	D	(V)~C	SD(V)	~0	~C
Mn	I	I	I	I	I	I	(N)I(V)	I	I	I	SI	(V)~0
Mo	D	D	(N)D(V)	D	D	D	D	D	D-0	D-0	~C	I
Na	SI	I	SI(V)	I	~C	I	SI	I	SI	I	I	~C
Ni	SD	SI(V)	I	I	SI	SI	C(0)	SD(V)	SI	SI	~C	SD or ~C(V)
pH	D	D	D	D	D	D	D	D	D	D	D	D
Si	I	I	I	I	SD(N)	(N)I(V)	I	I	I	I	I	SI(V)
SO_4	I	I	I	I	I	I	~C(V)	SI(V)	D	(V)SD(N)	(N)I(V)	~C
Sp. Cond.	I	SI	I	I	I	I	~C	~C	SD(V)	~C	~C	SD(V)
Sr	C	D	(N)I	D	SD	D	SD	D	SD	D	(N)D	D
TDS	I	I	I	I	I	I	(N)D(V)	I	(N)D(V)	~D(V)	~C	SI(V)
Ti	D	(N)SI(V)	(N)I(V)	(N)D(V)	~C(V)	SI	SD	SD	SD	SD(V)	(N)SD	0
V	D	(N)SI(V)	(N)I(V)	(N)D	~C(V)	(N)SI	0	SD	SI	(N)SD(V)	(N)SI	SD-0
Zn	C	(N)SI(V)	I	I	SI	SI	SI	SI	SI	SI	~0	~0(V)

D = decrease
I = increase
V = considerable variation
S = slight
N = net

TABLE D-47. PROTOCOL STEP 7 CONCENTRATION TRENDS AND MAXIMUM VALUES WITH REPETITIVE EXTRACTIONS

Element/ Species	Shale		Interburden		Sandstone		Limestone	
	Trend	Maximum	Trend	Maximum	Trend	Maximum	Trend	Maximum
Al	Steady increase	5.3	Increase net decrease	2.3	Increase to decrease	4.1	Net decrease	1.1
As	Net increase	0.57	Increase	1.5	Increase	0.6	Increase	0.69
B	Increase	2.1	Increase net decrease	1.1	Net increase	1.5	Increase then decrease	9
Ba	Decrease	0.036	Net Increase	0.12	Net slight increase	0.11	Slight increase	0.086
Ca	Decrease	180	Decrease	170	Decrease	180	Decrease	160
Cr	Net decrease	0.19	Decrease	0.22	Decrease then increase	0.16	Decrease	0.15
Cu	Ultimate increase too non DL*	0.018	Ultimate increase	0.021	Increase	0.025	Increase	0.02
F	Modest decrease	0.37	-	-	Decrease	0.47	Data incomplete	0.67
Fe	Fluctuates to increase	0.9	Fluctuates	0.12	Erratic	0.29	Erratic	0.16
Mg	Erratic	0.42	Fluctuates	0.042	Net increase	0.22	Increase	0.89
Mn	Erratic	0.03	Net increase	0.011	Erratic	0.005	Erratic	0.007
Na	Decrease	23	Decrease	23	Net decrease	23	Net decrease (erratic)	42
Ni	Erratic	0.11	Erratic	0.15	Erratic	0.2	Erratic	0.13
Pb	Occasional non DL	0.09	1 non DL value	0.074	Erratic	0.17	Erratic	0.33
pH	Decrease	to 9.3	Decrease min.	8.2	Decrease to min.	8.5	Decrease to min.	7.4
Si	Decrease	2.2	Decrease	2.2	Slight decrease	1.7	Slight decrease	1.6
Sp.Cond.	Decrease	1020	Decrease	1280	Decrease	1160	Decrease	1120
SO_4	Decrease	220	Net decrease	160	Net decrease	220	Data incomplete	200
Sr	Decrease	0.54	Decrease	0.5	Decrease	0.45	Decrease	0.97
Ti	Erratic occasional Non DL	0.012	Slight increase	0.0095	Erratic	0.012	Erratic	0.023
V	-	-	~DL one value	0.019	DL one value	0.017	~DL (2 values)	0.025
Zn	Decrease	0.086	Erratic to increase	0.75	Decrease	0.1	Decrease	0.093

*DL = Detection Limit

interstitial water in the solid sample rather than reductions in basic constituents of the soil matrix or "sorbed" species.

Several species decreased consistently with Step 7 repetition for all four media. These were Ca, Na, Sr, and SO_4. Silicon was reduced slightly, and chromium decreased overall but occasionally increased in the intermediate steps. Specific conductance also decreased as would be expected with decreases in the major ion species, calcium and sulfate.

Copper increased modestly with repeated leaching, but erratic variations were seen. Decreased pH could be the major factor. Similar observation might be directed at the intermediate increase in chromium prior to final decreasing concentrations.

The rest of the solution species monitored did not follow a clear pattern. Fluctuations were seen with occasional increases in species at or below detection limits to values slightly above these limits.

D.7.5.2 One-Day Versus Seven-Day Contact for Step 7

Average values for the A/B pairs of Step 7, repetition one are tabulated in Table D-48 for the one-day and seven-day contact times. More typically than not, concentration values for the seven-day samples were higher than for the one-day samples. The number of species showing an increase for seven days over one day were 11, 4, 9 and 14 respectively for shale, interburden, sandstone, and Greer limestone. Corresponding numbers of species showing a decrease were 3, 4, 3 and 4 respectively. For the interburden and sandstone, five and three species, respectively, showed essentially no change, with the different contact times. The pH values were not included in the above accounting. Slight pH increase was seen for the shale and sandstone, but no change was seen for interburden and Greer limestone.

When detection limit values were recorded in both samples, those species were not included in the talley.

TABLE D-48. COMPARISON OF PROTOCOL STEP 7 FIRST REPETITION VALUES FOR ONE- AND SEVEN-DAY CONTACT TIMES[1]

Element/ Species	Shale		Interburden		Sandstone		Limestone	
	1 day	7 days	1 day	7 days	1 day	7 days	1 day	7 days
Al	0.64	0.81	0.34	0.35	0.81	0.54	0.67	0.46
B	–	–	–	–	–	–	–	0.2
Ba	0.026	0.040	0.030	0.032	0.041	0.043	0.032	0.06
Ca	120	160	150	170	120	170	120	150
Cr	0.16	0.078	0.16	0.22	0.2	0.037	0.22	0.076
F	–	0.34	0.73	0.53	0.6	0.44	0.33	0.63
Fe	0.13	0.61	0.064	0.049	0.14	0.2	0.09	0.055
Mg	0.030	0.130	0.014	0.012	0.052	0.05	0.045	0.071
Mn	0.003	0.017	–	<0.001	–	0.008	–	0.0015
Na	20	14	22	22	24	9.8	23	13
Ni	0.02	0.09	–	<0.02	0	0.11	–	0.03
pH[2]	11.1	11.3	11.5	11.5	10.6	11.4	11.4	11.4
Pb	–	–	–	–	–	–	–	0.10
Si	1.6	2.2	1.3	2.2	0.95	1.7	0.93	1.6
SO_4	120	200	130	160	87	190	130	170
Sp.Cond.[3]	1020	990	1310	1270	1110	1160	960	1110
Sr	0.29	0.5	0.39	0.6	0.43	0.44	0.31	0.89
V	–	0.015	0.01	<0.01	–	–	–	0.015
Zn	0.038	0.083	0.044	0.11	0.041	0.087	0.067	0.091

NOTE: Values are averages of replicate pairs.

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

Some elements were consistent in their change with all four media. Increases were seen for Ca, Ni, Si, Zn, and SO_4. Barium appeared to increase slightly, and strontium increased in three of four cases. No decrease was seen for a given species for all four media, but chromium decreased with increased contact in three of the four systems as did sodium (the fourth showed no change with time of contact for sodium).

D.7.5.3 Comparison of Step 7 Maximum Values with Step 4 and Media Step 1 Values

For convenience of comparison, Table D-49 contains a tabulation of the maximum values obtained in the Step 7 procedure, the Step 1 media leachate (with deionized water) and the Step 4 leachate value for three media. Also presented for comparison are the maximum and median values obtained for all of the Step 1 Exxon PFBC waste leachates.

Of note in the table are those species for which the maximum Step 7 value exceeded both the Step 4 and media Step 1 leachate values. These were aluminum, boron and chromium for all three media. Sodium and zinc were higher for two media each and iron was higher for a single medium.

Several other species were higher for the Step 7 solutions than for the final step 4 value but were lower than the media leachates. Cu, Mg, Mn, Ni, Sr, Ti, V, and F behaved in this fashion for one or more of the media. Only strontium was consistent for all three media.

The differences in behavior between the media leachates and the other two (Step 7 and Step 4) likely relates in part to pH differences. Step 7 pH values (and Step 4) were always high initially and then generally declined upon successive repetitions of the step. Usually (but not always) the maximum value for the Step 7 species was obtained for the earlier steps in the repetitions. More detailed understanding of the pH effect would result from a point by point comparison.

TABLE D-49. SUMMARY COMPARISONS OF CONCENTRATIONS IN EXXON PFBC WASTE LEACHATES (STEP 1, STEP 4, STEP 7) AND DISPOSAL MEDIA LEACHATES (STEP 1) FOR THREE MEDIA[1]

			Shale			Interburden			Sandstone		
Element/ Species	Exxon Step 1 Median Value	Exxon Step 1 Maximum Value	Step 7 Maximum	Step 1 Medium Leach	Step 4 Final	Step 7 Maximum	Step 1 Medium Leach	Step 4 Final	Step 7 Maximum	Step 1 Medium Leach	Step 4 Final
Al	0.8	1.5	5.3	<0.25	<0.25	2.3	<0.25	0.29	4.1	<0.25	0.62
As	0.04	0.04	0.57	-	-	0.54	-	-	0.6	-	-
B	11	16	2.1	0.06	0.79	1.1	0.07	0.29	1.5	0.05	0.28
Ba	0.18	0.3	0.036	0.12	0.38	0.12	0.92	0.05	0.11	0.14	0.15
Ca	1660	1900	180	52	510	170	28	1240	180	22	890
Cd	DL	DL	-	<0.04	-	-	<0.04	-	-	<0.04	-
Cr	0.1	0.2	0.19	0.015	0.007	0.11	0.14	0.085	0.16	<0.005	0.046
Cu	DL	0.09	0.018	<0.005	0.44	0.021	0.088	0	0.025	<0.005	0.061
F	0.83	1.9	0.37	0.39	0.23	-	0.125	0.94	0.47	1	0.3
Fe	0.17	0.39	0.9	0.055	0.61	0.12	0.235	0.1	0.29	<0.04	0.31
Mg	0.68	6.3	0.42	7.1	0.04	0.042	9.65	0.052	0.22	4.4	0.001
Mn	0	0.01	0.03	0.13	0.38	0.011	0.185	0	0.005	<0.006	0.009
Na	17	34	23	2.1	-	23	1.4	24	23	3.4	0
Ni	0.01	0.26	0.11	0.07	0.36	0.15	0.26	0.01	0.2	<0.015	0.1
Pb	-	0.03	0.09	-	-	0.074	13.5	-	0.17		-
pH[2]	11.9	12.6	11.3	8.0	11.4	11.5	5.5	12.0	11.4	8.2	11.8
Si	0.78	2.8	2.2	3.7	0.68	2.2	13.5	1	1.7	3.8	0.6
SO_4	1210	1260	220	68	720	160	140	1170	220	15	980
Sr	2.8	4.2	0.54	0.13	1.4	0.5	0.195	3.2	0.45	0.007	2.3
Ti	-	0.16	0.012	<0.025	0.34	0.0095	<0.025	0	0.012	<0.025	0.04
V	-	0.33	-	<0.015	0.32	0.019	<0.015	0	0.017	<0.015	0.08
Zn	0.11	0.3	0.086	0.02	0.36	0.75	0.26	0.18	0.1	0.015	0.009

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

Only for aluminum did the Step 7 maximum values exceed the maximum Step 1 waste leachate value for all three media. The iron value for shale also exceeded the waste Step 1 maximum values.

D.8 Laboratory Column Leaching Results

The laboratory leaching columns contained both wastes and disposal media. Raw data for the individual columns are listed in Appendix J. A summary of concentration behavior with time is presented in Table D-50. Ranges of concentration and patterns with time of elution are presented as a condensation of 120 individual plots of the data. Additional descriptions and interpretations of the trends are given in Appendix I.

D.8.1 Comparison of Behavior of Ground and Unground Waste

Columns LC-2 and LC-3 are column pair containing ground and unground Exxon PFBC waste. Ranges of concentrations in leachates from these two columns were generally the same except for magnesium and manganese, which were below detection limits for the ground waste but at rather high values for the unground waste leachate. Maximum values for chloride were appreciably higher in the ground waste leachate while higher maximum values were seen for copper and potassium in the unground waste leachate. Generally, the behavior was similar with time of elution.

D.8.2 Assessment of Waste and Disposal Media Combinations

Comparison of Column LC-1 with Column LC-4 data and Column LC-2/LC-3 with Column LC-5 data provides an assessment of attenuation behavior of Alliance AFBC waste with shale and Exxon PFBC waste with sandstone, respectively. The comparisons are made on the basis of the last two sampling periods only, thus allowing for stabilization of the two systems.

For the Alliance AFBC and shale combination, increases in concentrations after passage through the shale medium were seen for B, Mg, Mn, and F. Species attenuated were calcium, lithium, and sulfate. TDS and specific

TABLE D-50. SUMMARY OF LEACHATE CONCENTRATIONS AND TIME BEHAVIOR FOR THE LABORATORY LEACHING COLUMNS[1]

Element/ Species	Column LC-1 Sandstone and Unground Alliance AFBC Waste		Column LC-2 Shale and Ground Exxon PFBC Waste		Column LC-3 Shale and Unground Exxon PFBC Waste		Column LC-4 Sandstone and Ground Alliance AFBC Waste		Column LC-5 Shale and Ground Exxon PFBC Waste	
	Range[2]	Trend	Range[2]	Trend	Range[2]	Trend	Range[2]	Trend	Range[2]	Trend
Al	-	—	0-1.25	∪↘	0-1.8	∪↘	0-3.8	∪↘	0-1.5	∩↘
B	1.5-4.0	∪∩↘	3-25	↓	3-24	↓	1-5.8	∩∪∩↓	1-13	∿∩→
Ba	0.4-1.2	↗	0.3-1.2	↑	0.35-0.9	∩∪↗	0.3-0.9	∩∪↑	0.3-1.2	∩∪↗
Ca	700-1300	∩∪↗	350-1000	∪∩↘	300-900	↳	300-1300	↳	250-1300	↳
Cl	0-1200	↘	10-4000	↓	30-260	↓	0-1300	↓	20-210	↳
Cr	0-0.33	∪↗	0-0.33	↘	0-0.4	↓	0-0.22	↳	0-0.25	↳
Cu	-		0.05-0.10	∪∩→	0.03-0.76	∩↘	0-0.125	E[3]	0-0.09	∩∪∩↗
F	0.25-0.55	↳	0.3-0.8	∩↘	0.25-0.65	↓	0.3-0.5	↳	0.28-0.68	↳
Fe	0-0.18	∪∩↘	0-0.18	∩∪∩↘	0-0.35	∩↘	0-0.7	E	0-0.84	∪↗
K	<100-1000	∪∩↘	100-400	↘	300-2500	∩↘	75-200	∩∪∩↓	38-65	↗
Li	0.25-2.25	∪∩↘	0.2-4	↓	0-3.3	∩↘	0-0.4	∪∩↘	0-0.07	∩∪↗
Mg	0-0.38	∪↗	-	—	0-80	∩→	0-350	∩→	2-130	∩→
Mn	-	—	-	—	0-0.4	∪↗	0-1.8	∩∪↗	0-1.1	↗
Mo	0.3-0.95	↗	0-2.8	↘	0.1-2.4	↓	0-0.11	∩∪↗	0-0.3	∩∪↗
pH	11.5-12.2	∩∪↗	11.3-12.5	↓	11.5-12.3	∩↘	7.0-7.8	∪↗	7.3-9.0	↓
Sp. Cond.	5700-7800	∪∩∪↗	4000-9000	∩↓	2500-8200	∩↘	1500-5500	↘	2000-4000	∪∩↘
SO_4	1000-1500	↓	1500-3000	∩↘	1250-2900	∩↘	600-2700	∩↘	1500-3500	∩→
TDS	3000-7000	∩∪→	3000-7000	∩↘	2000-7000	∩↘	1000-7000	↘	2000-5000	∪∩↘
TIC	-	—	-	—	-	—	15-52	∩↘	6-35	∪↗

[1] See Figure D-5 for column configurations.
[2] Concentrations in mg/L except for pH and conductance (microsiemens).
[3] E = Erratic

conductance paralleled the calcium and sulfate reductions. A major difference in pH was observed and likely caused some of the effects seen, notably release of magnesium. Higher inorganic carbon in the Column LC-4 leachate may be related to reduced calcium because of precipitation of calcium carbonate. Other species were apparently little changed.

Al, Ca, K, Li, pH, specific conductance, and TDS were reduced for the Exxon PFBC (ground) waste upon passage through the sandstone medium (comparison of Column LC-2 and Column LC-5 data). Sulfate did not show appreciable reduction, unlike the Column LC-4 data set. Species mobilized were Fe, Mg, Mn, and Mo. Additional interpretation of attenuation on the lab leaching columns is contained in Appendix I.

D.9 Evaluation of Experimental Design Factors

During the middle and latter stages of the program, several supplementary investigations were undertaken to study the effects of experimental design and to assist in the interpretation of the data obtained.

D.9.1 Filtered Versus Unfiltered Samples

Statistical analysis of the Step 1 leachates for the Alliance AFBC waste was conducted for the data set generated in the Step 1 reproducibility study. The details of this analysis are presented in Appendix H. The raw data are contained in Appendix J. With the exception of strontium (mean values of 22 and 23 mg/L), the differences in mean values for samples that were centrifuged only and samples that were centrifuged followed by filtration were not statistically significant. These results suggest that the wide variability seen in some Exxon PFBC and Alliance AFBC extraction data is not attributable to problems with unfiltered samples.

D.9.2 Ground Versus Unground Samples

Two separate investigations of the effect of grinding the waste samples for the protocol were performed.

Initial Studies

For the Exxon PFBC waste, four replicate Step 1 extractions were conducted on unground wastes. The average of these four values for the various parameters is presented in Table D-51 (second column). The overall averages for the Step 1 leachates from ground waste are presented in the third column. The fourth column contains the ratio of unground to ground leachate concentration. Nine of the elements have ratios that are 10 or more. Eight of the nine have a factor of 10 higher concentration in the ground waste; one is in the opposite direction. Another five show a ratio greater than two. There does appear to be a pattern. Differences appear mostly for the trace metals. Higher values seem to occur for the unground wastes, implying that grain size reduction may lead to reduction of solution concentrations in the solutions extracted from ground waste, possibly via readsorption of outer surface deposited materials.

Subsequent Studies

Another test of the effect of grinding was conducted late in the study. As part of the reduced protocol performed on the Georgetown AFBC wastes, parallel Step 1 and 2 extractions were conducted in duplicate on ground and unground waste. The raw data are contained in Appendix J, where ground wastes are designated by replicates A and B. Unground wastes are designated as replicates C and D. An analysis was performed to evaluate the differences between the two. Species which were prodominantly undetected for both ground and unground wastes were not considered. As a result, analyses were performed for Ba, Ca, Cr, F, K, Li, Mg, Na, Si, SO_4, Sr, TDS, TOC, and pH.

Plots of concentration vs. volume per mass for ground and unground waste samples are displayed for Na, TOC, K, and TDS in Figures D-48 to D-51. The volume of leachate per mass of waste is 10 for protocol Step 1 and 10(i + 1) for protocol Step 2, iteration i.

For all species analyzed, it was observed that the curves for the ground and unground cases had very similar shapes, as in the four plots

TABLE D-51. STEP 1 LEACHATE CONCENTRATIONS FOR EXXON PFBC WASTES: GROUND VERSUS UNGROUND[1]

Element/ Species	Unground (UG) Waste	Ground (G) Waste	UG/G Ratio
Al	1.2	0.61	1.9
B	5.1	13	0.38
Ba	0.27	0.17	1.6
Ca	1460	1700	0.86
Cd	<0.005	0.0025	-
Co	1.6	0.075	22
Cr	0.13	0.062	2.2
Cu	0.058	0.0025	23
F	1.3	0.79	1.7
Fe	0.11	0.22	0.48
K	710	20	36
Mg	0.27	1.9	0.14
Mn	0.012	0.00005	240
Mo	2.5	-	-
Na	15	17	0.87
Ni	0.22	0.014	15
pH[2]	12.5	11.8	NC[3]
Si	2.4	0.67	3.5
SO_4	1150	1230	0.93
Sr	2.73	2.9	0.93
Ti	0.15	0.001	150
TOC	1.3	1.1	1.2
V	0.25	0.005	51
Zn	0.013	0.17	0.076

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[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] NC = Log quantities; ratio not computed.

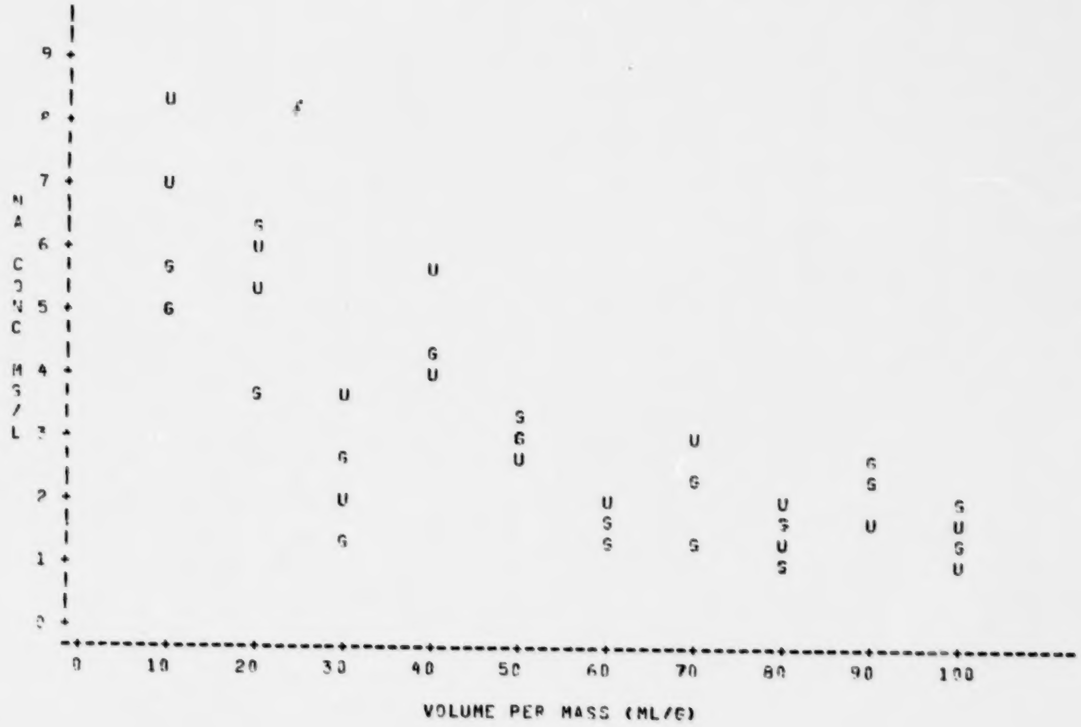


Figure D-48. Comparison of Sodium Concentration as a Function of Volume per Mass for Leachates from Ground and Unground Georgetown AFBC Waste.

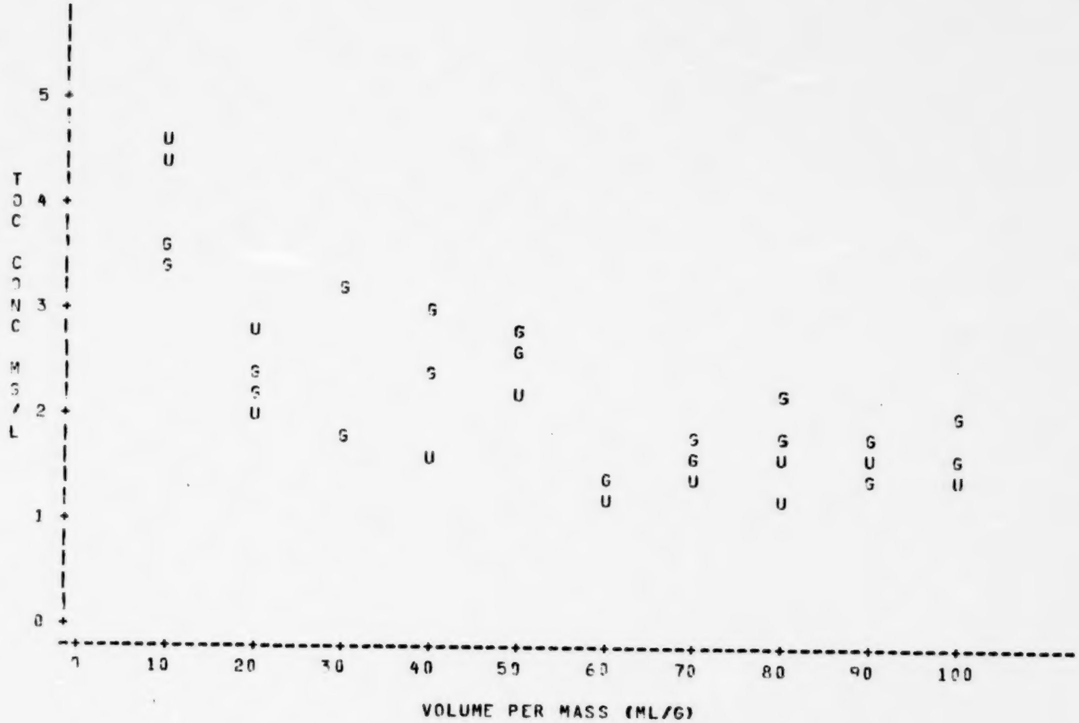


Figure D-49. Comparison of Total Organic Carbon Concentration Trends as a Function of Volume per Mass for Leachates from Ground and Unground Georgetown AFBC Waste.

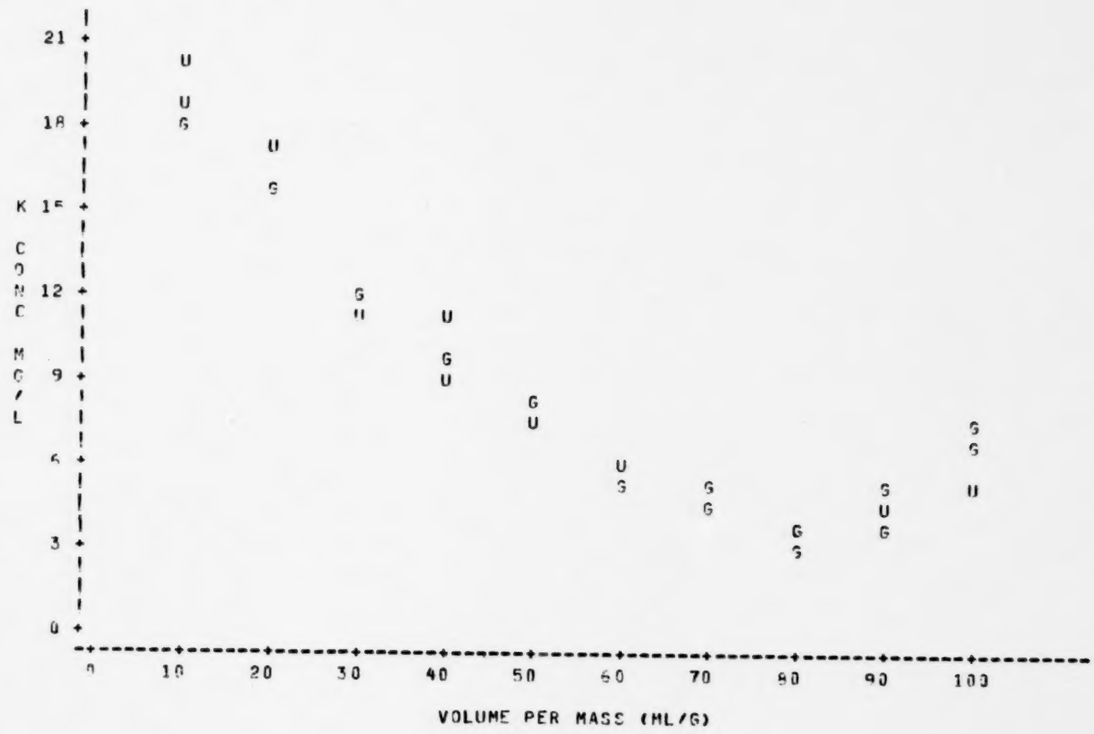


Figure D-50. Comparison of Potassium Concentration Trends as a Function of Volume per Mass for Leachates from Ground and Unground Georgetown AFBC Waste.

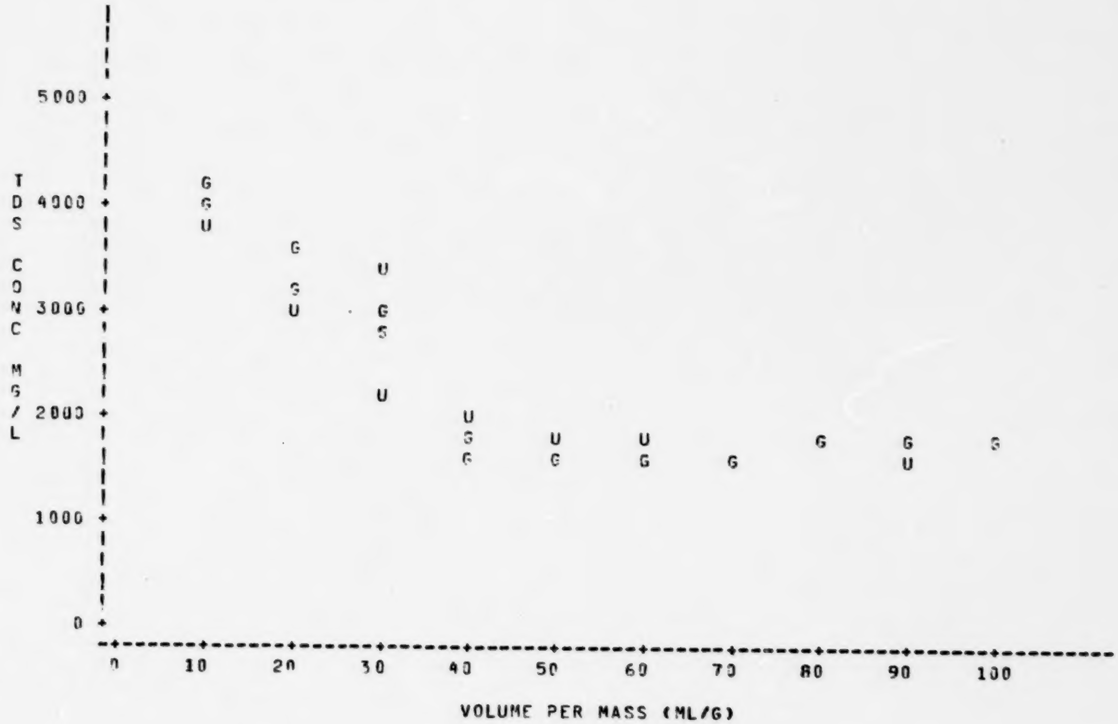


Figure D-51. Comparison of Total Dissolved Solids Concentration Trends as a Function of Volume per Mass for Leachates from Ground and Unground Georgetown AFBC Waste.

presented here. It was also observed in some instances that the points for the ground and unground cases were clearly separated for a volume per mass of 10 mG/L (Step 1) but were mixed for larger volumes per mass. This effect is particularly evident for Na and TOC in the plot shown here.

Thus, general linear models procedures were used to test the following:

1. After the common trend with volume per mass was explained (by a cubic polynomial in volume per mass) and the overall average difference between the ground and unground cases had been accounted for, did the points for the ground and unground cases differ significantly for Step 1?

2. After the common trend with volume per mass and the difference (if any) for Step 1 had been explained, did the ground and unground cases differ on the average overall?

Table D-52 presents the results of these analyses. There are a number of significant differences between the ground and unground cases for Step 1. Of these, the concentration is higher for the ground waste in three cases and for the unground waste in five cases. pH is slightly higher (12.54 vs. 12.47) for the unground waste. After the Step 1 difference is explained, the differences between the ground and unground cases are significant on the average only for Li and pH.

D.9.3 Reproducibility Studies

The analytical data from the Step 1 reproducibility study are contained in Appendix J. The statistical analyses and assessment of this study are presented in Appendix H. Not contained in that assessment, however, is an examination of the individual Step 1 percent extractions from the solids. Table D-53 contains this information and presents the standard deviation obtained for the five replications.

TABLE D-52. STATISTICAL COMPARISON OF RESULTS FOR GROUND AND UNGROUND WASTES FOR PROTOCOL STEPS 1 AND 2 FOR THE GEORGETOWN AFBC WASTE

		Protocol Step 1					Protocol Steps 1, 2				
		Ground		Unground			Ground		Unground		
Element/ Species	Standard Error[1] (mg/L)	Mean (mg/L)	N	Mean (mg/L)	N	Difference Significant[1]?	Mean (mg/L)	N	Mean (mg/L)	N	Difference Significant[1]?
Ba	0.61	0.19	2	0.19	2	No	1	20	1	20	No
Ca	99	1600	2	1500	2	Yes	1000	19	1000	20	No
Cr[2]	0.018	0.046	2	0.1	2	Yes	0.03	6	0.057	6	No
F	0.029	0.13	2	0.21	2	Yes	0.085	20	0.096	20	No
K	0.75	18	2	20	2	Yes	8.9	20	8.7	20	No
Li	0.063	0.49	2	0.6	2	No	0.17	19	0.22	20	Yes
Mg	0.86	3	2	2	2	Yes	0.78	20	1	20	No
Na	0.99	5.3	2	7.6	2	Yes	2.8	20	3.4	20	No
pH	0.033	12.5	2	12.5	2	No	12.5	20	12.5	20	Yes
Si	0.73	2.5	2	3.4	2	No	1.3	20	1.6	20	No
SO_4[3]	200	1500	2	1300	2	No	1200	6	1200	6	No
Sr	0.69	14	2	13	2	No	2.8	20	2.8	20	No
TDS	260	4100	2	3800	2	Yes	2200	20	2200	20	No
TOC	0.41	3.5	2	4.5	2	Yes	2.3	20	2	20	Yes

[1] At 0.10 level. The significance tests were performed using general linear models procedures. The standard error is the standard deviation of the scatter about the regression function.

[2] Predominantly undetected with some scatter detected values beyond 30 mL/g in volume per mass.

[3] Predominantly undetected beyond 30 mL/g. Values beyond 30 mL/g for Cr and SO_4 were not included in the analysis.

TABLE D-53. PERCENT OF TOTAL SOLIDS CONTENT LEACHED FROM THE FIVE ALLIANCE AFBC SOLIDS IN STEP 1 OF THE PROTOCOL

Element/ Species	Percent of Total Solids Content Leached						Standard Deviation of Percent Leached
	Sample A	Sample B	Sample C	Sample D	Sample E	Average Percent Leached	
Al	0.08	0.04	0.03	0.06	0.05	0.05	0.02
Ba	2.1	2.1	2.1	2.1	2.6	2.2	0.24
Be	0.19	0.35	0.23	0.22	0.31	0.26	0.064
Ca	4.6	4.7	4.3	4.5	4.8	4.6	0.2
Cl	62	61	64	63	61	62	1.5
Co	2.1	3	2.7	2.3	2.3	2.5	0.36
Cr	0.42	0.55	0.12	0.64	1.8	0.70	0.63
Cu	1.1	0.57	0.19	1.1	1.7	0.93	0.57
F	0.53	0.59	0.79	1	0.84	0.75	0.19
Fe	0.002	0.001	0.001	0.019	0.002	0.005	0.008
K	17	15	17	17	20	17	1.7
Li	23	31	23	22	23	25	3.9
Mg	0.26	0.10	0.13	0.19	0.17	0.17	0.06
Mo	11	16	23	16	16	16	4.3
Na	14	14	16	17	21	16	2.9
Si	0.02	0.01	0.01	0	-	0.01	0.01
SO_4	11	12	14	9.2	10	11	1.7
Sr	39	37	38	39	40	39	1.2
Ti	-	0.033	-	0.023	0.023	0.026	0.006
V	1.9	2.7	-	2.8	2.8	2.6	0.42
Zn	5.2	0.28	4.6	0.23	0.4	2.1	2.5

Compared with the data of Table D-12 for the Alliance AFBC waste, good agreement for the percent of the solids leached by the Step 1 procedure was found for Ca, Cl, Co, Cu, Mo, and Si. Modest agreement (that is, to within roughly a factor of two) was seen for Al, Be, Cr, SO_4, Sr, Ti, and V. Poorer agreement was found for B, Ba, F, Fe, K, and Zn. High standard deviations on a relative basis are indicated for all components of this group in Table D-53.

In all cases, the agreement between the data of Table D-12 (which contains the original solids composition data for the original Step 1 leaching of the Alliance AFBC waste) and in Table D-53 is within an order of magnitude and more generally closer to a factor of four.

D.10 References

D-1. Lowenback, W.A., February 1978, Compilation and Evaluation of Leaching Test Methods, MTR-7758, Mitre Corporation.

D.2. Ham, R.K., M.A. Anderson, R. Stegmann, and R. Stanforth, August 1978, Background Study on the Development of a Standard Leaching Test, Final Report, EPA Grant R-804773-01.

D-3. Ham, R.K., M.A. Anderson, R. Stegmann, and R. Stanforth, October 1978, Comparison of Three Waste Leaching Tests, Final Report, EPA Grant R-804773-01 extension.

D-4. Sun, C.C., C.H. Peterson, R.A. Newby, W.G. Vaux, and D.L. Keairns, March 1978, Disposal of Solid Residues from Fluidized Bed Combustion: Engineering and Laboratory Studies, EPA 600/7-78-049.

D-5. "National Interim Primary Drinking Water Standards," Code of Federal Regulations, Title 40, Part 141.

D-6. "National Secondary Drinking Water Regulations," Code of Federal Regulations, Title 40, Part 143.

D-7. Cleland, J.G., and G.L. Kingsbury, November 1979, Multimedia Environmental Goals for Environmental Assessment, Volumes I and II, EPA-600/7-77-136a and -136b, Research Triangle Institute, Research Triangle Park, North Carolina.

D-8. McQuaker, Neil R., Paul D. Kluckner, and Gok N. Chang, 1979, Analytical Chemistry, Vol. 51, p. 888.

D-9. Federal Register, 3 December 179, Vol. 44, No. 233, pp. 69559-64.

D-10. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, March 1979, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020.

D-11. Baumann, Elizbeth W., 1968, Analytical Chimica Acta, Vol. 42, p. 127.

D-12. Baker, R.L., 192, Analytical Chemistry, Vol. 44, p. 1326.

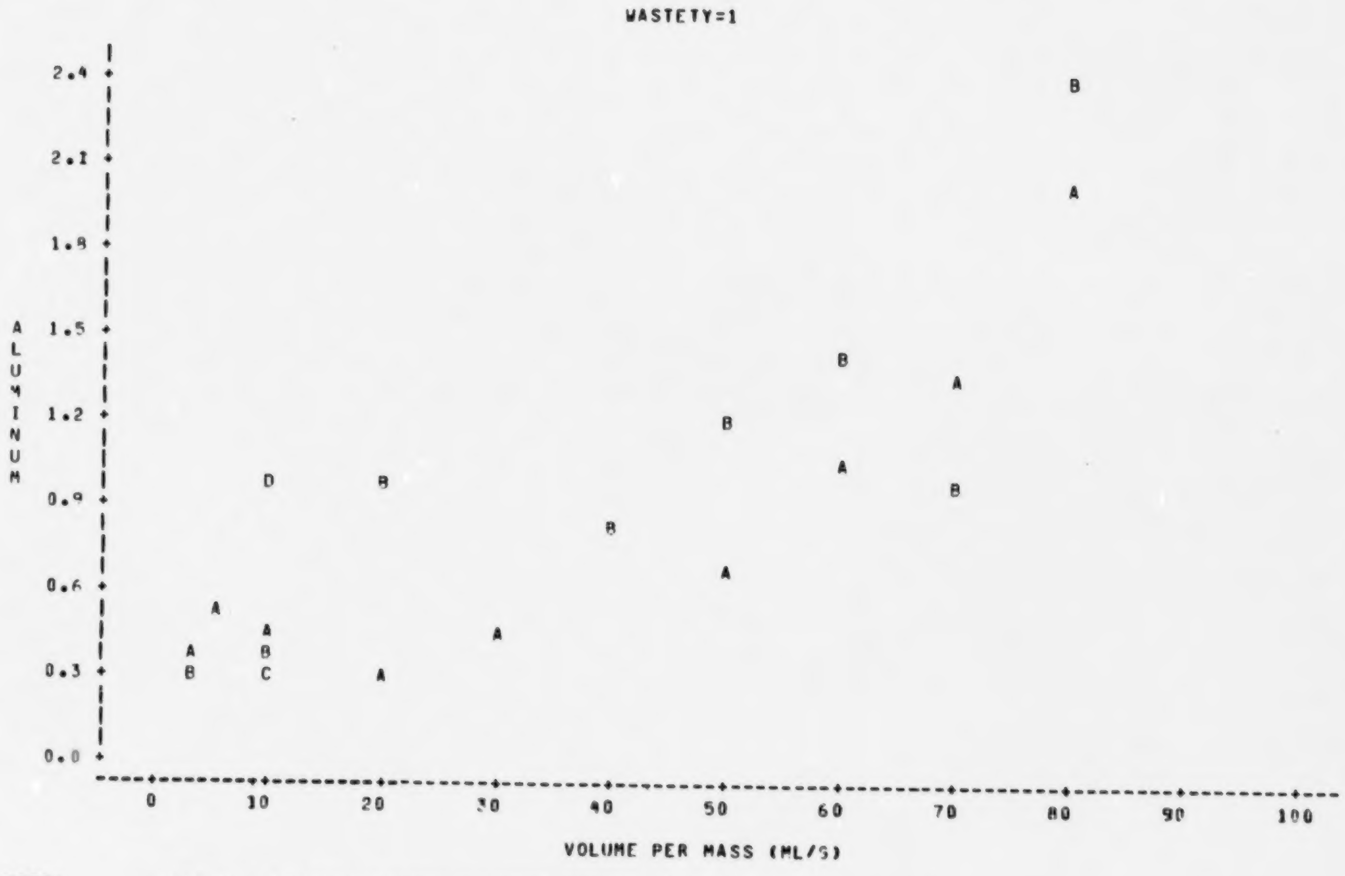
D-13. Environmental Protection Agency, July 1976, Quality Criteria for Water.

D-14. Sun, C.C., R.A. Newby, and D.L. Kairns, 1980, Impact of the Resource Conservation and Recovery Act on FBC Residue Disposal, EPA Contract No. 8-02-3110, EPA Industrial Environmental Research Laboratory.

Appendix D

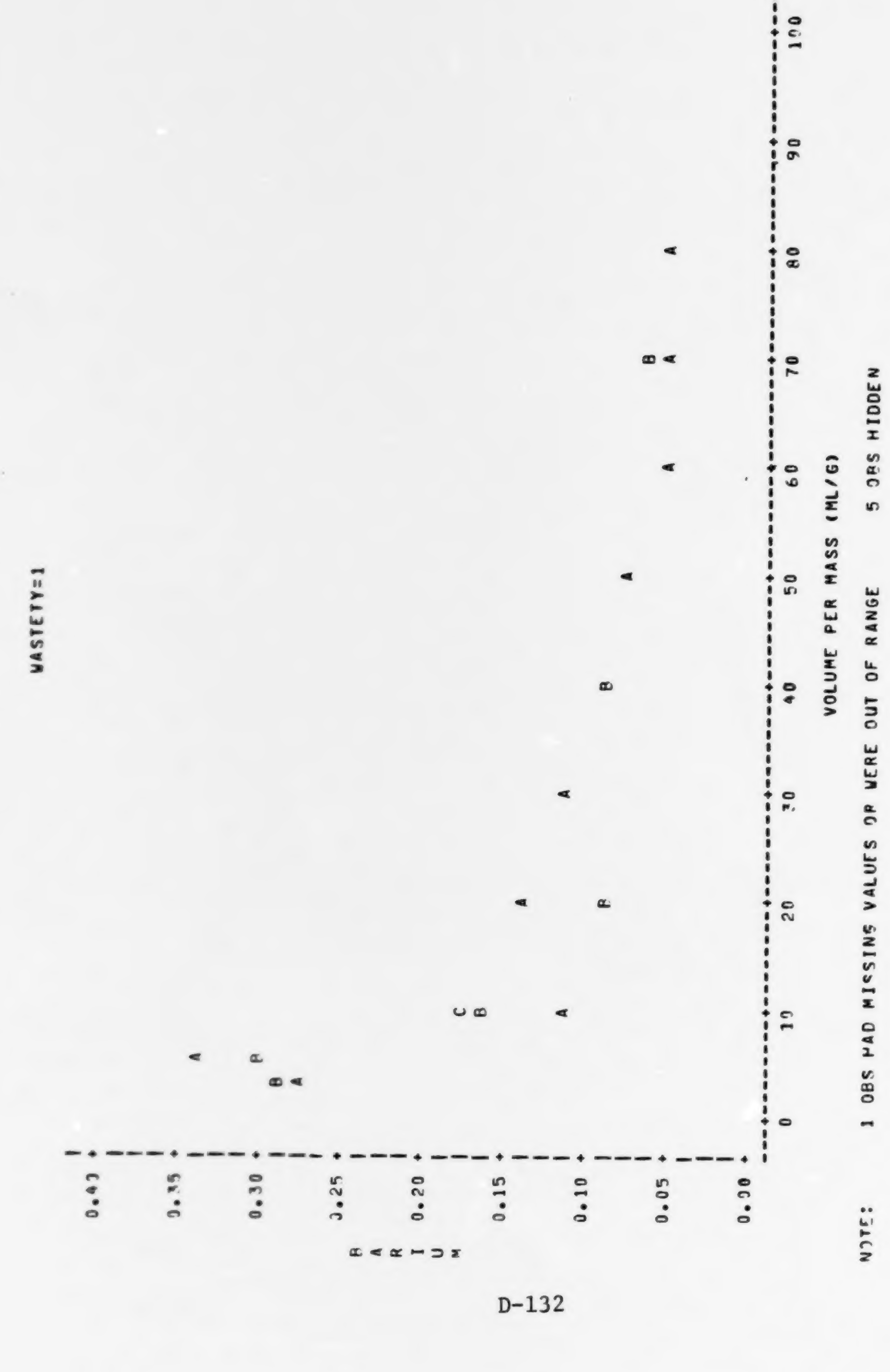
Attachment 1

Figures D-9 to D-35



NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 2 OBS HIDDEN

Figure D-9. Concentration of Aluminum (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.



NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 5 OBS HIDDEN

Figure D–10. Concentration of Barium (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.

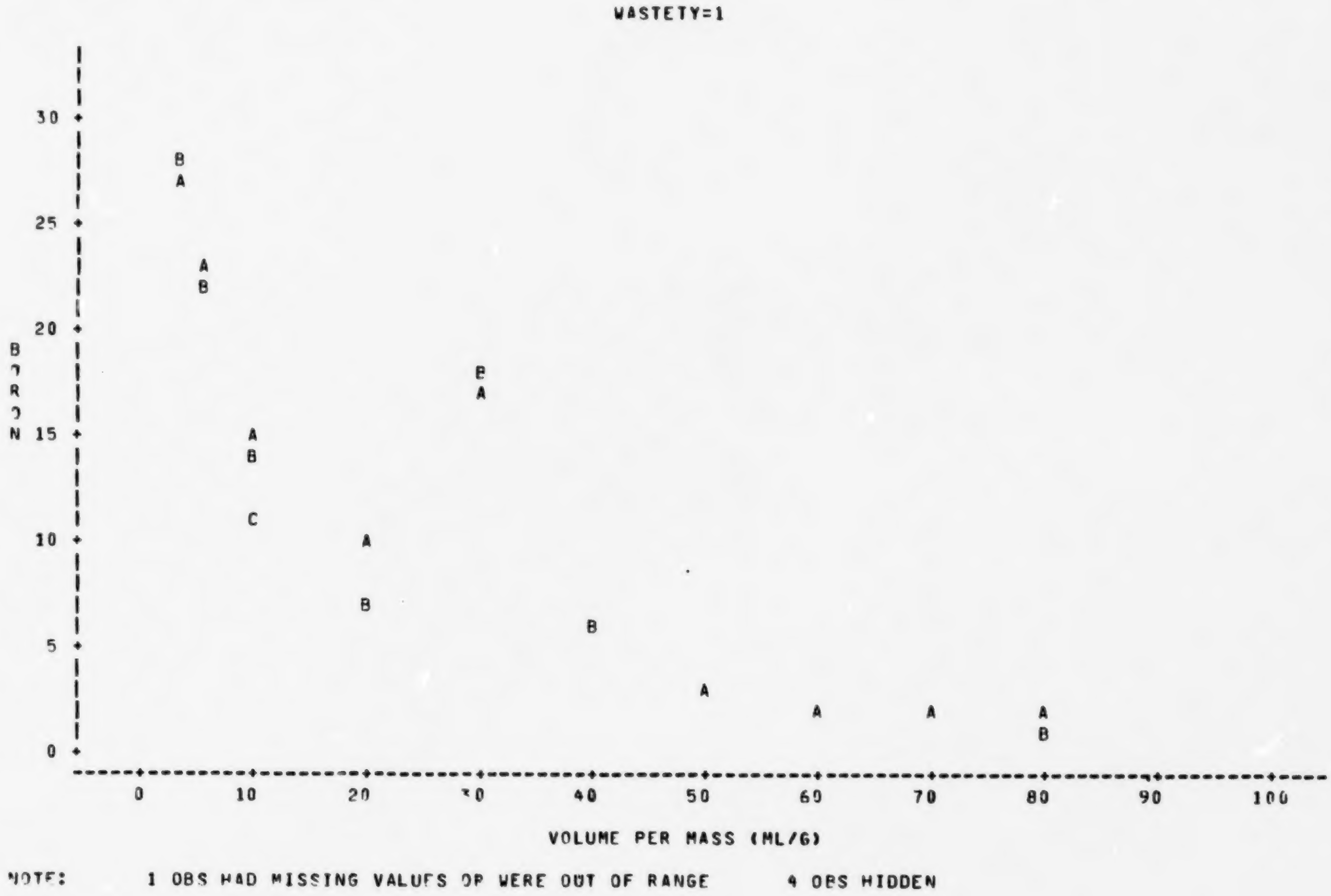
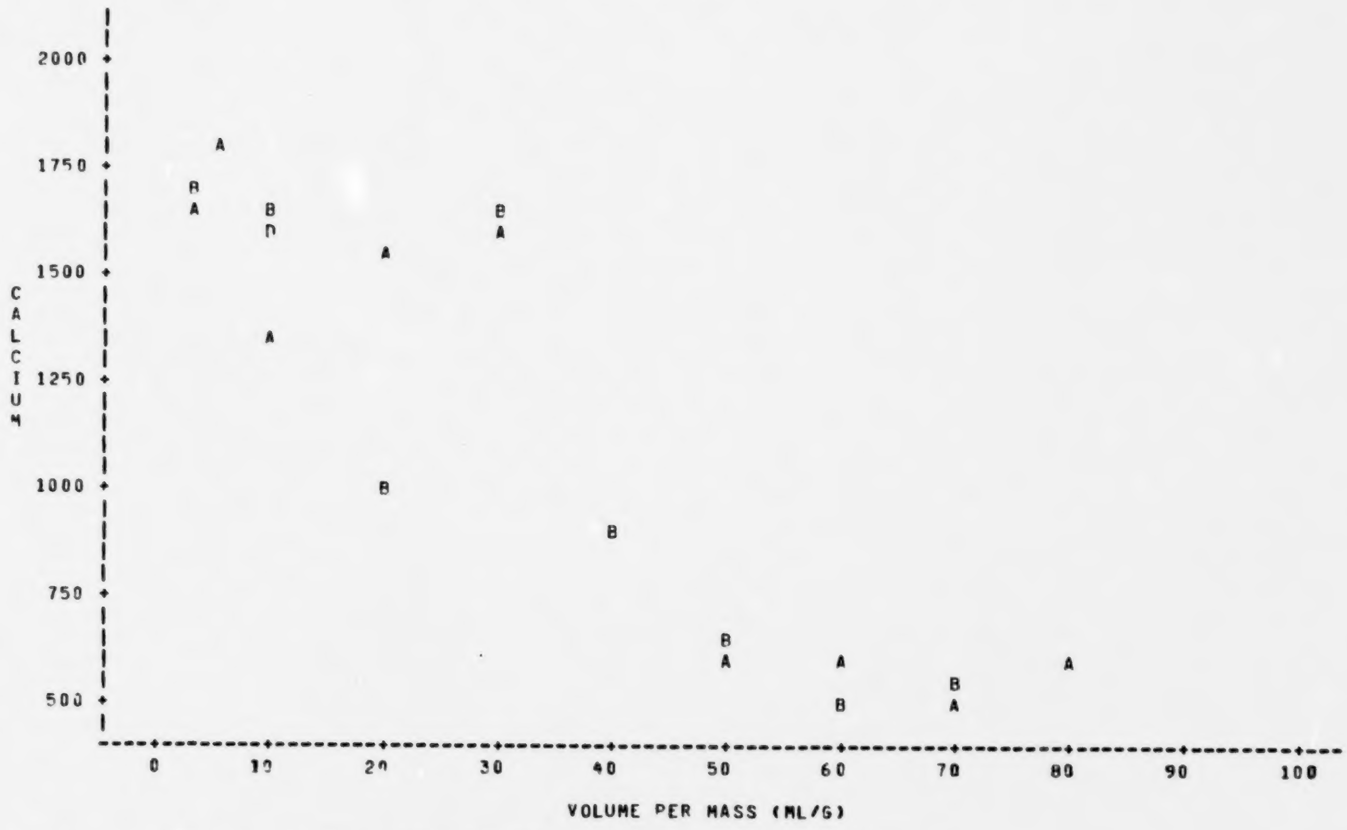


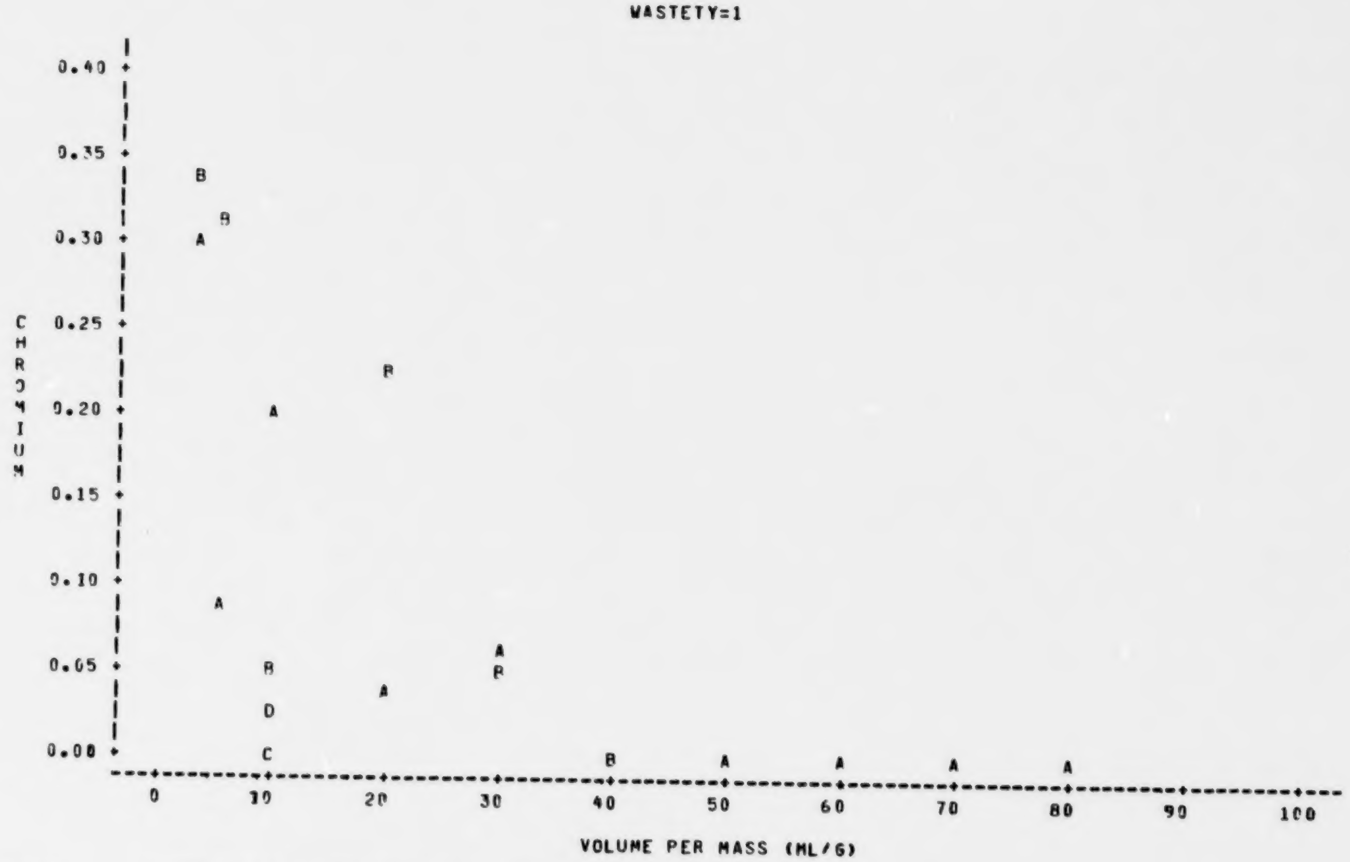
Figure D-11. Concentration of Boron (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.

WASTETY=1



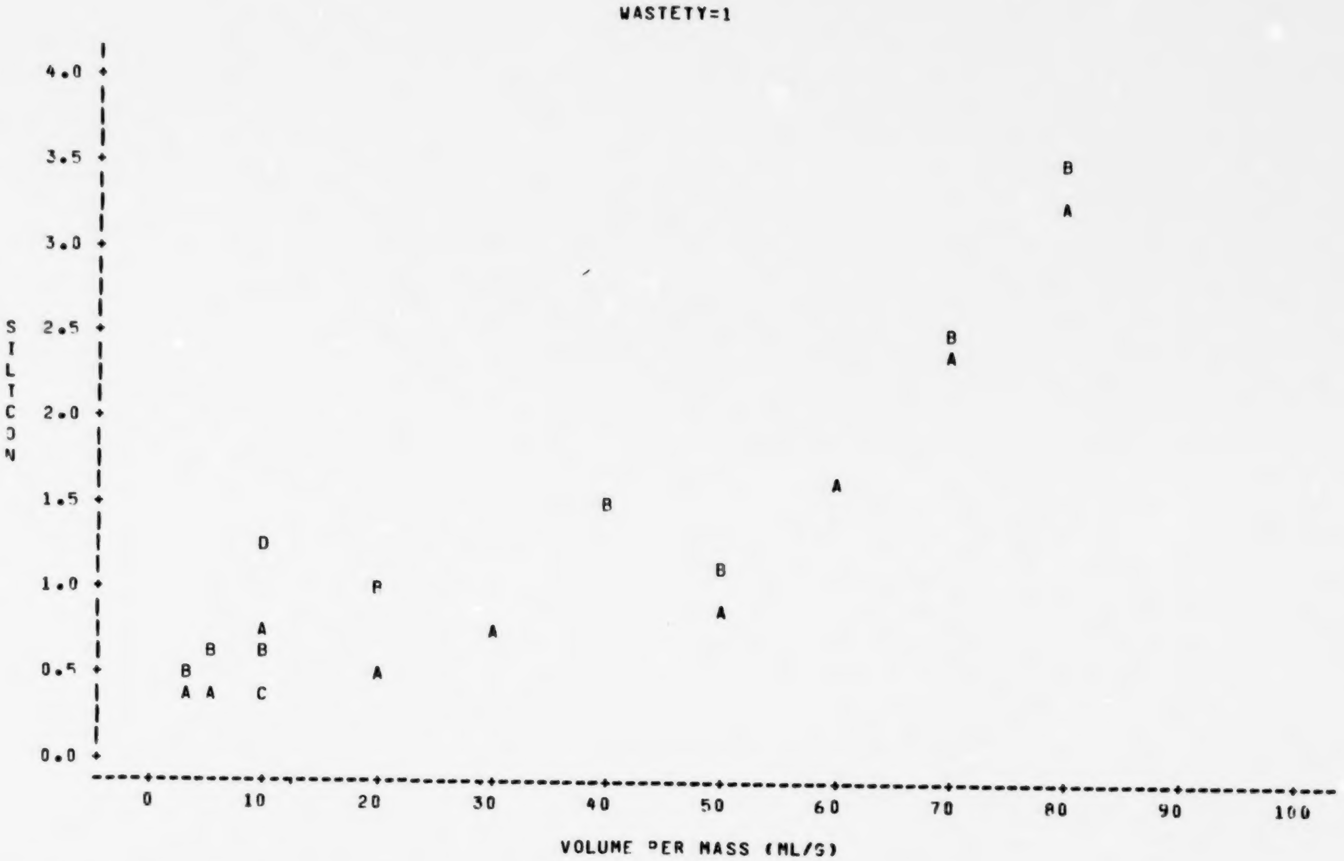
NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 3 OBS HIDDEN

Figure D-12. Concentration of Calcium (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.



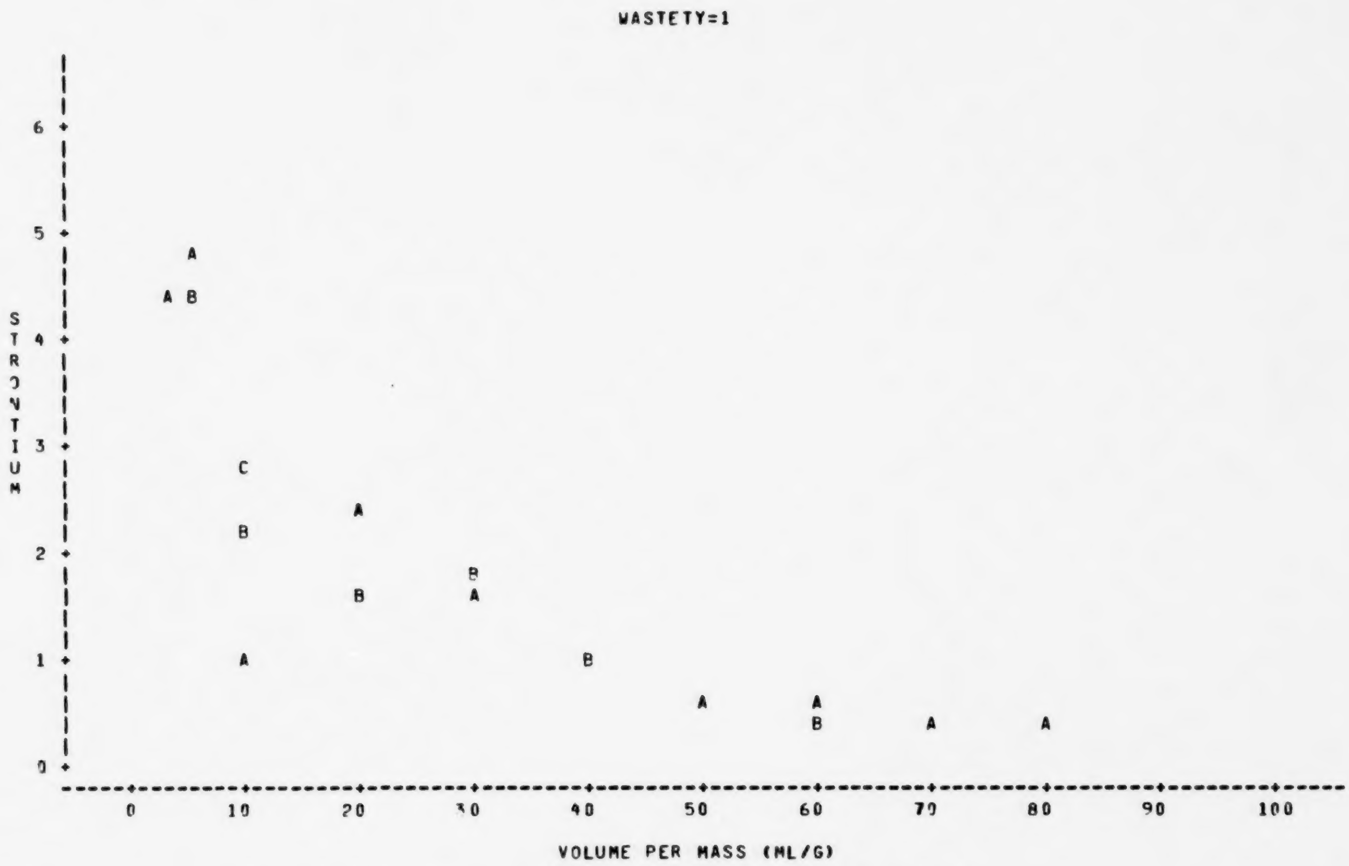
NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 4 OBS HIDDEN

Figure D-13. Concentration of Chromium (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.



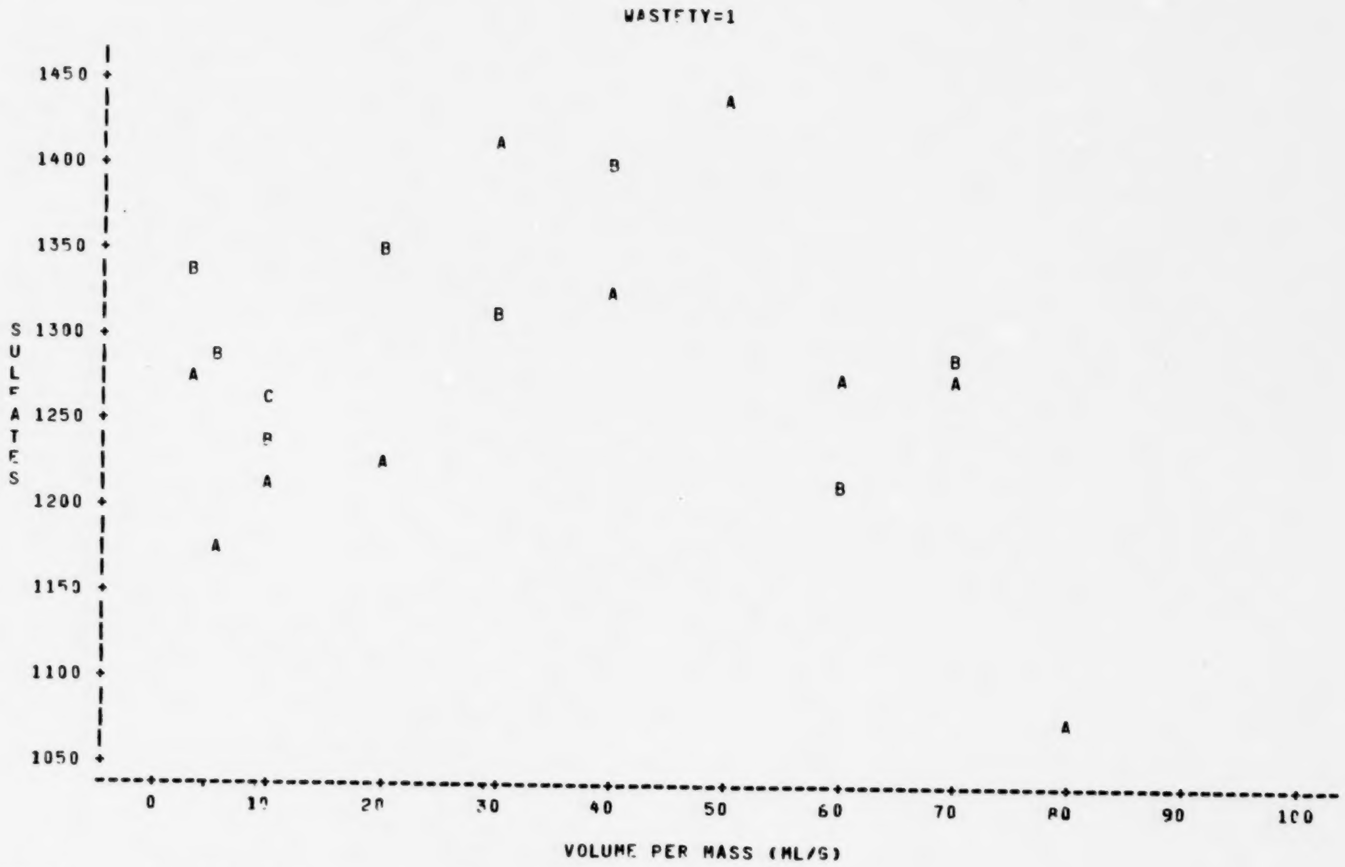
NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 2 OBS HIDDEN

Figure D-14. Concentration of Silicon (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.



NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 5 OBS HIDDEN

Figure D-15. Concentration of Strontium (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.



NOTE: 3 OBS HIDDEN

Figure D-16. Concentration of Sulfate (mg/L) as a Function of Volume per Mass (mL/g) for Exxon PFBC Waste Leachate.

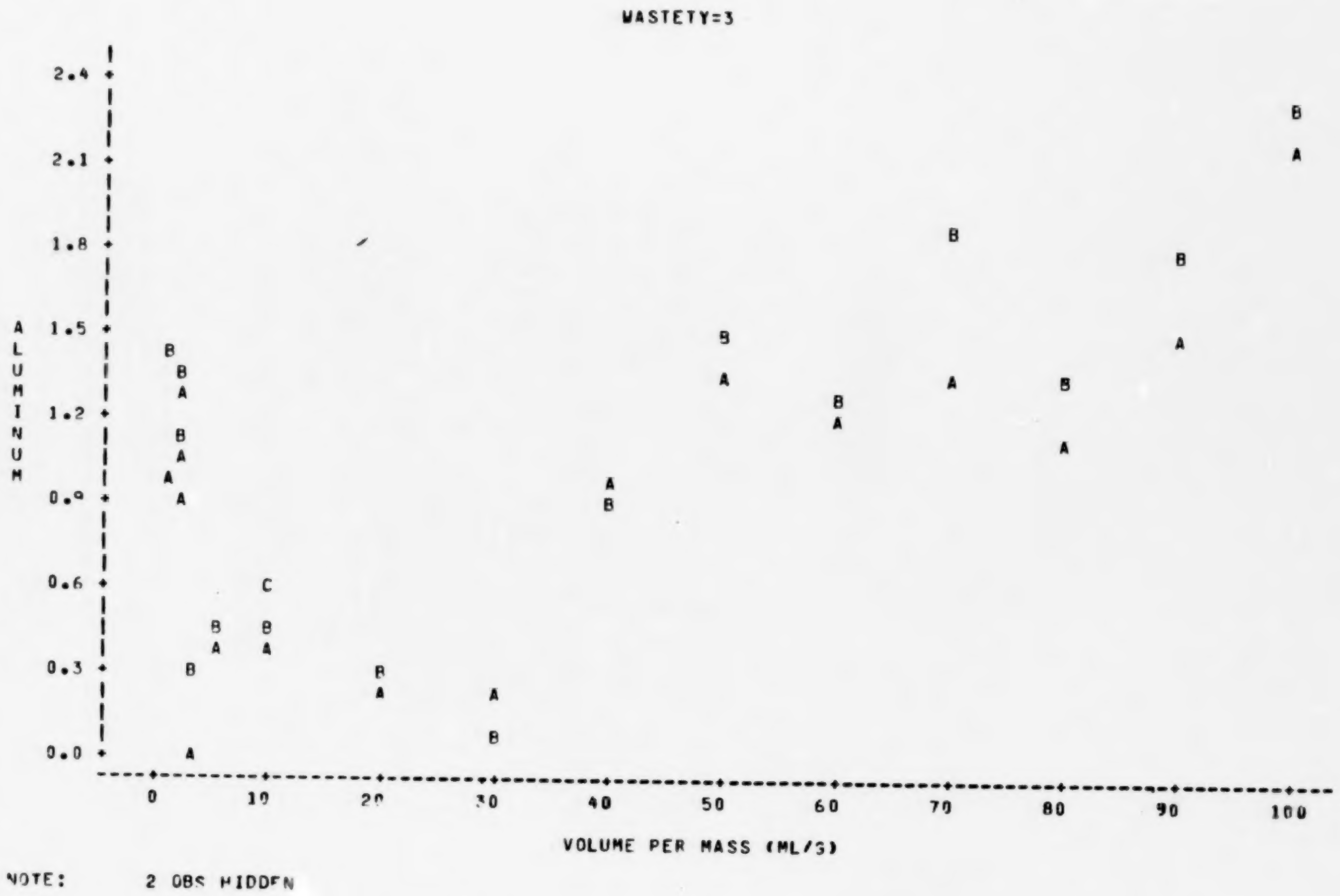


Figure D-17. Concentration of Aluminum (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

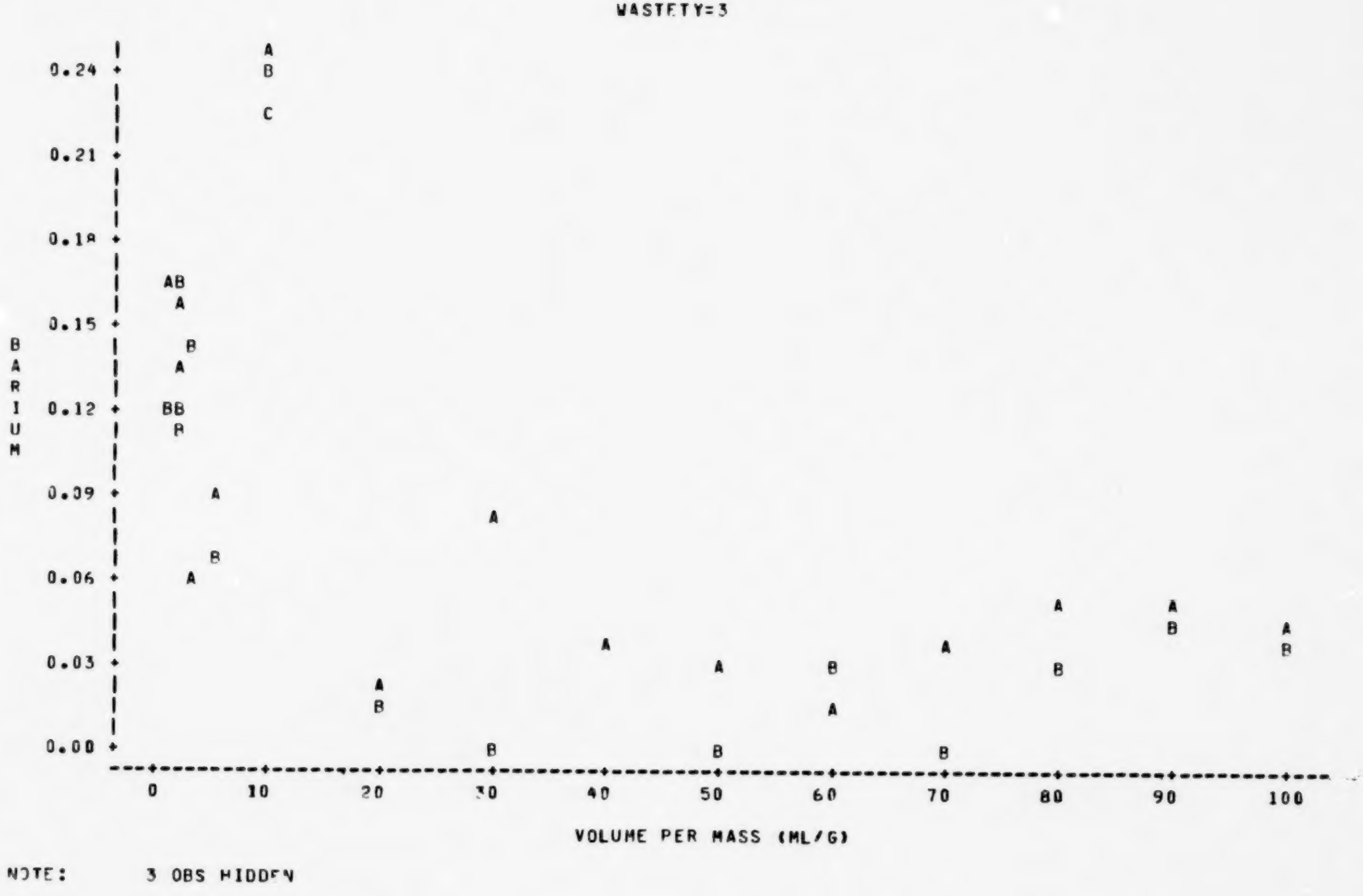


Figure D-18. Concentration of Barium (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

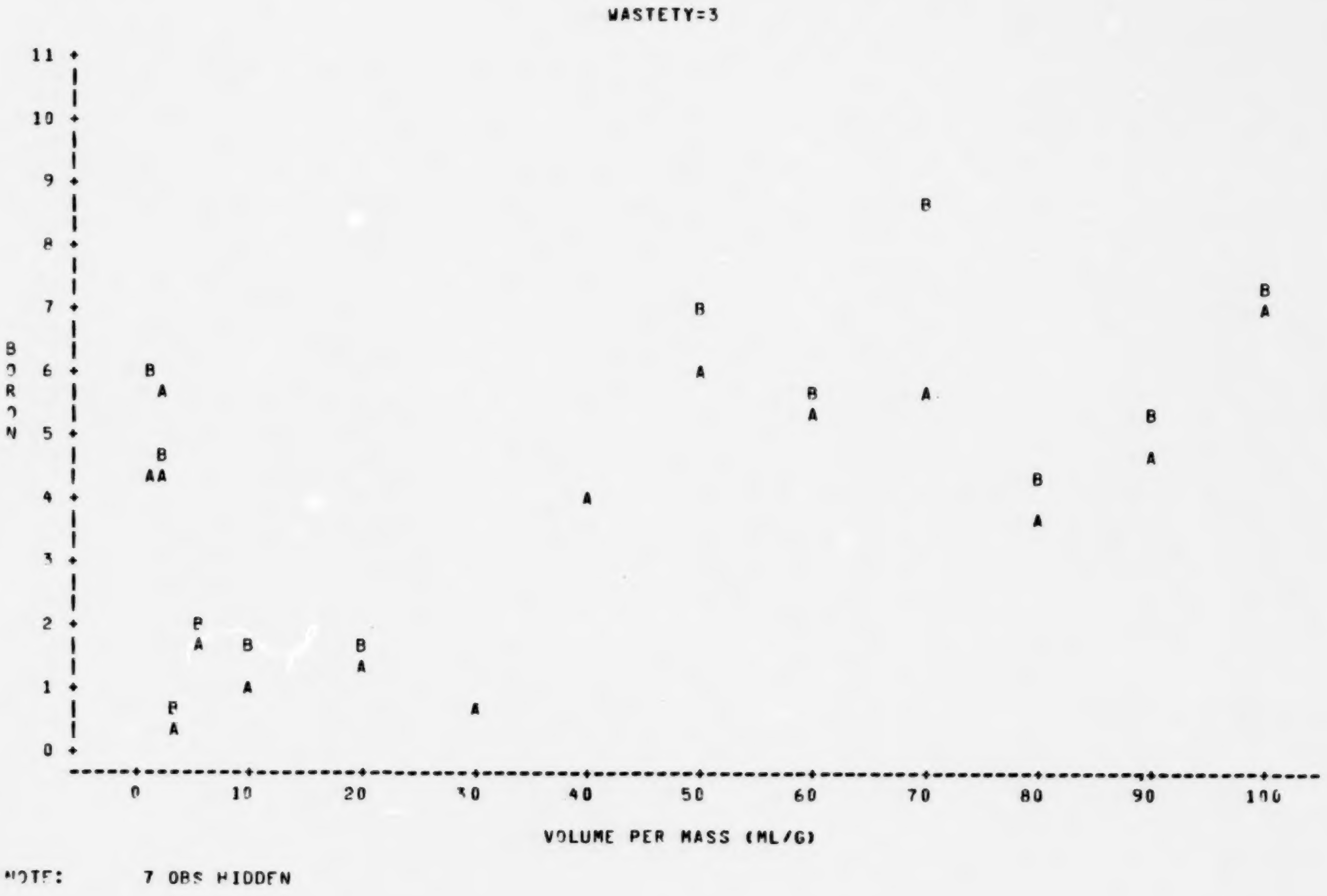
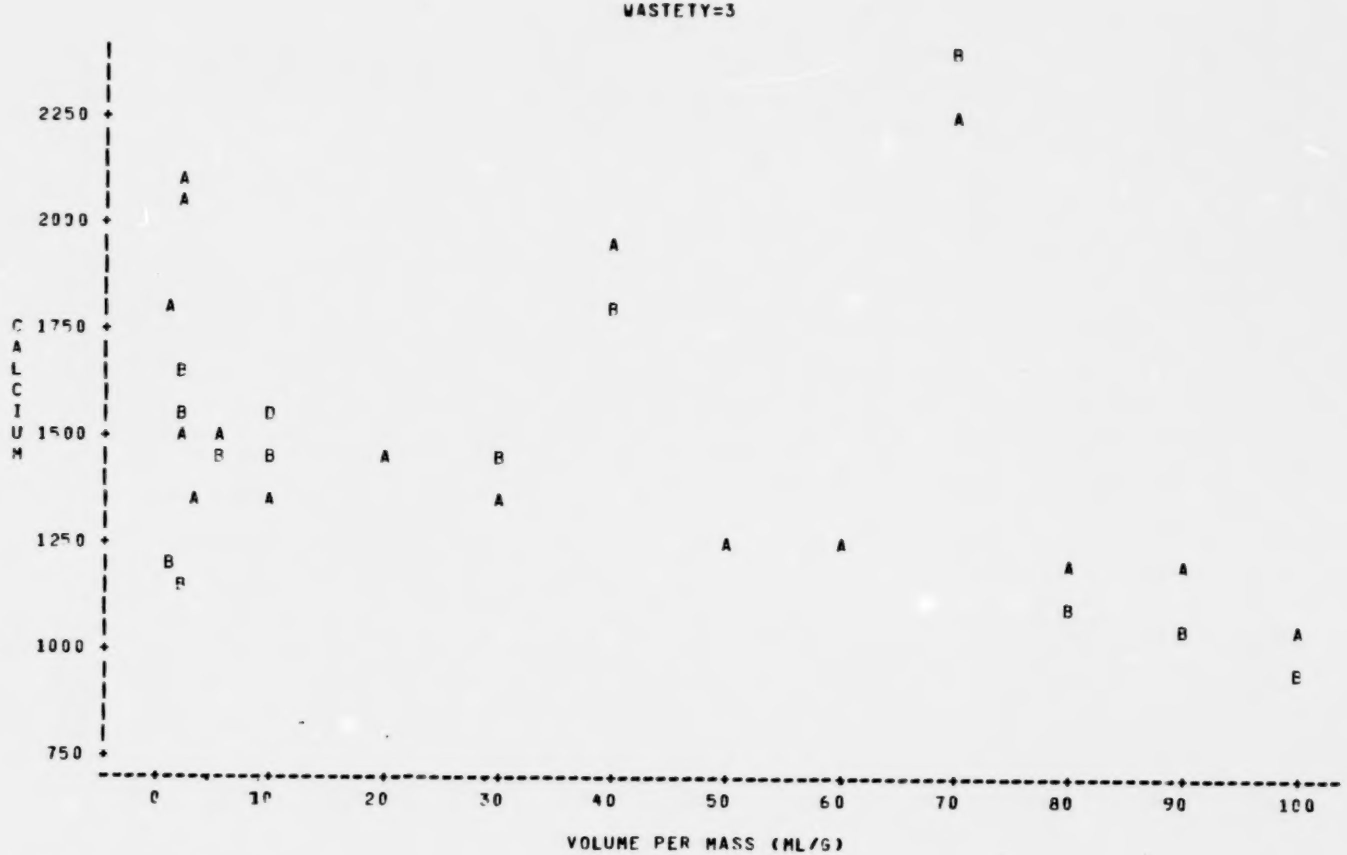


Figure D-19. Concentration of Boron (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.



NOTE: 5 OBS HIDDEN

Figure D-20. Concentration of Calcium (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

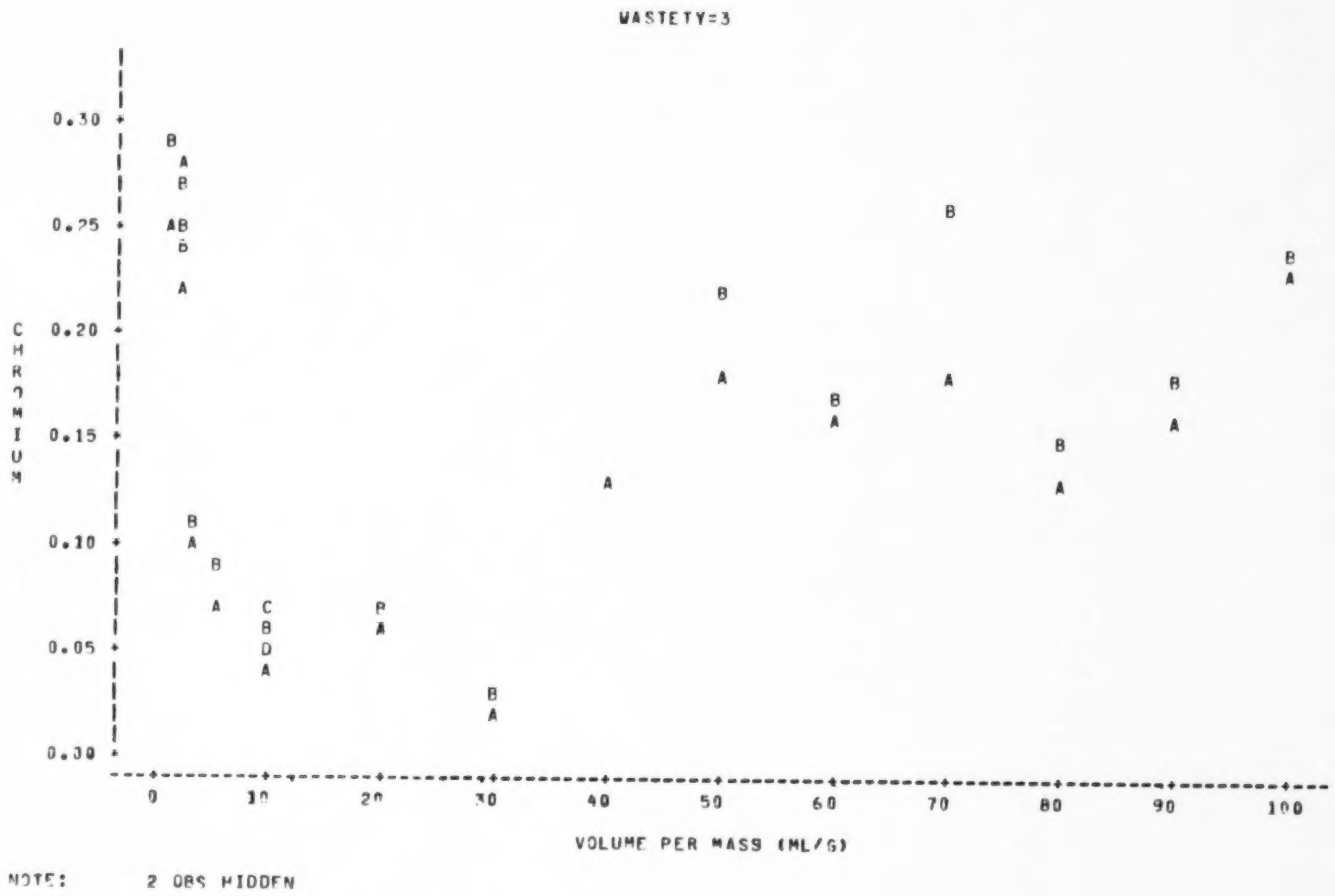


Figure D-21. Concentration of Chromium (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

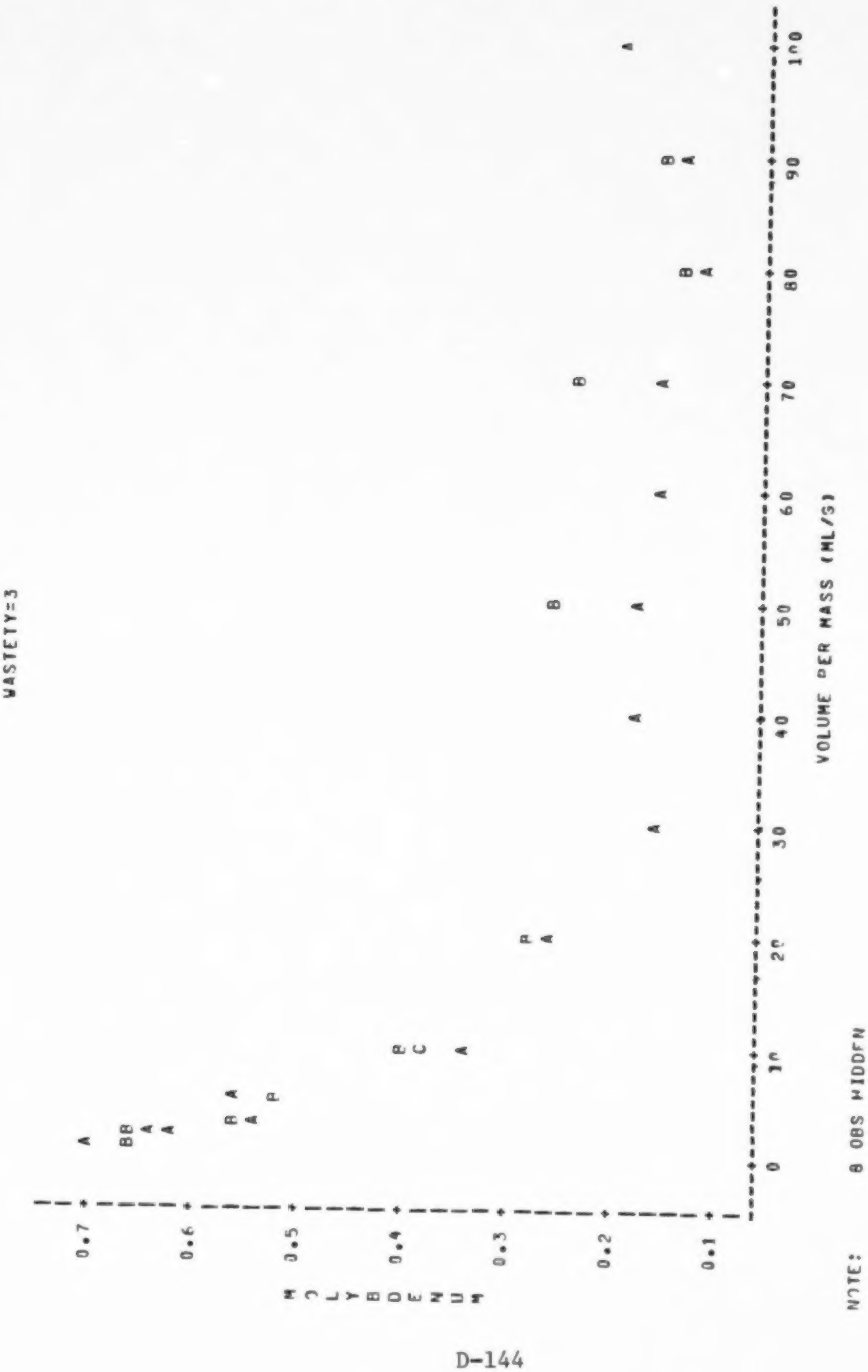


Figure D-22. Concentration of Molybdenum (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

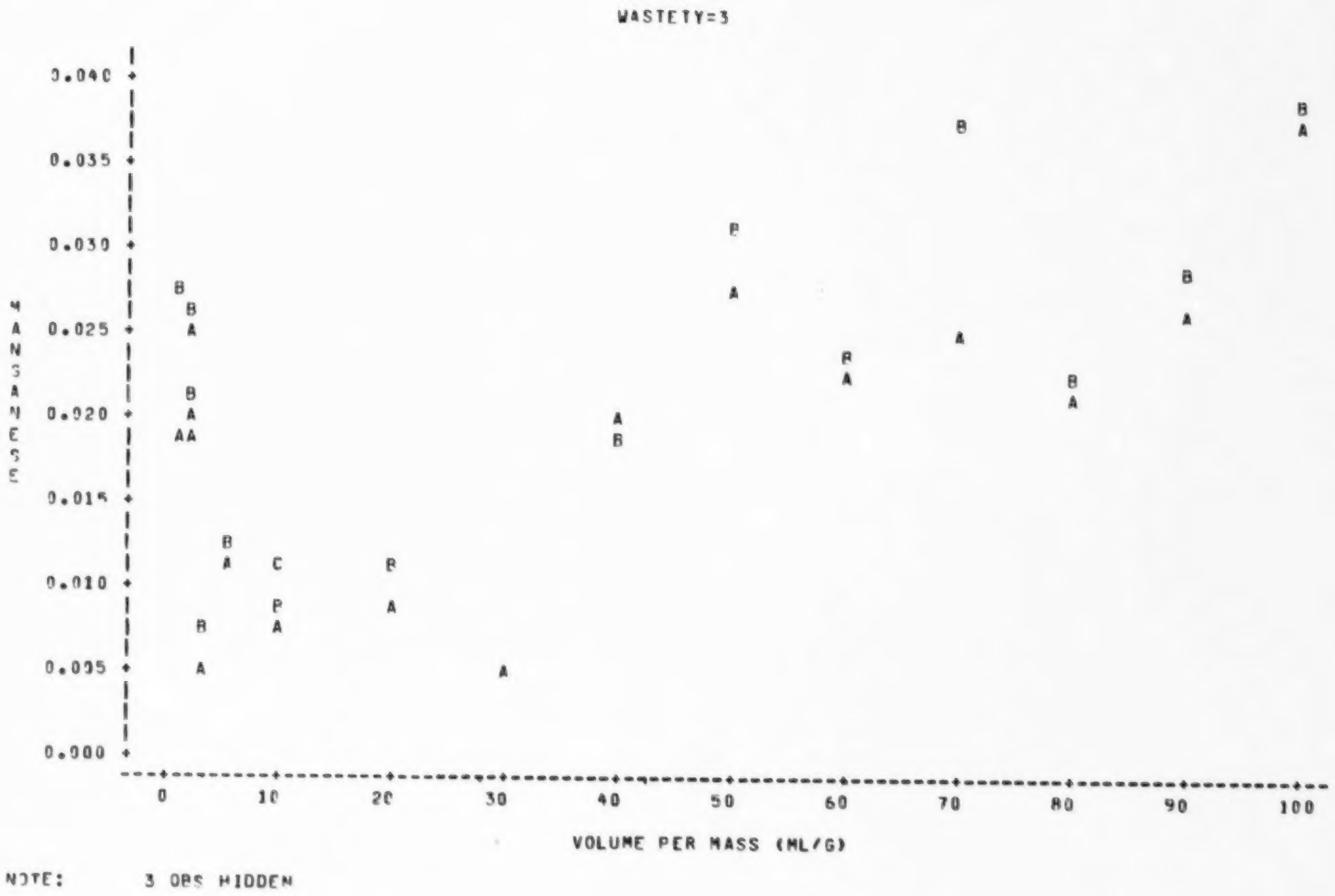


Figure D-23. Concentration of Manganese (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

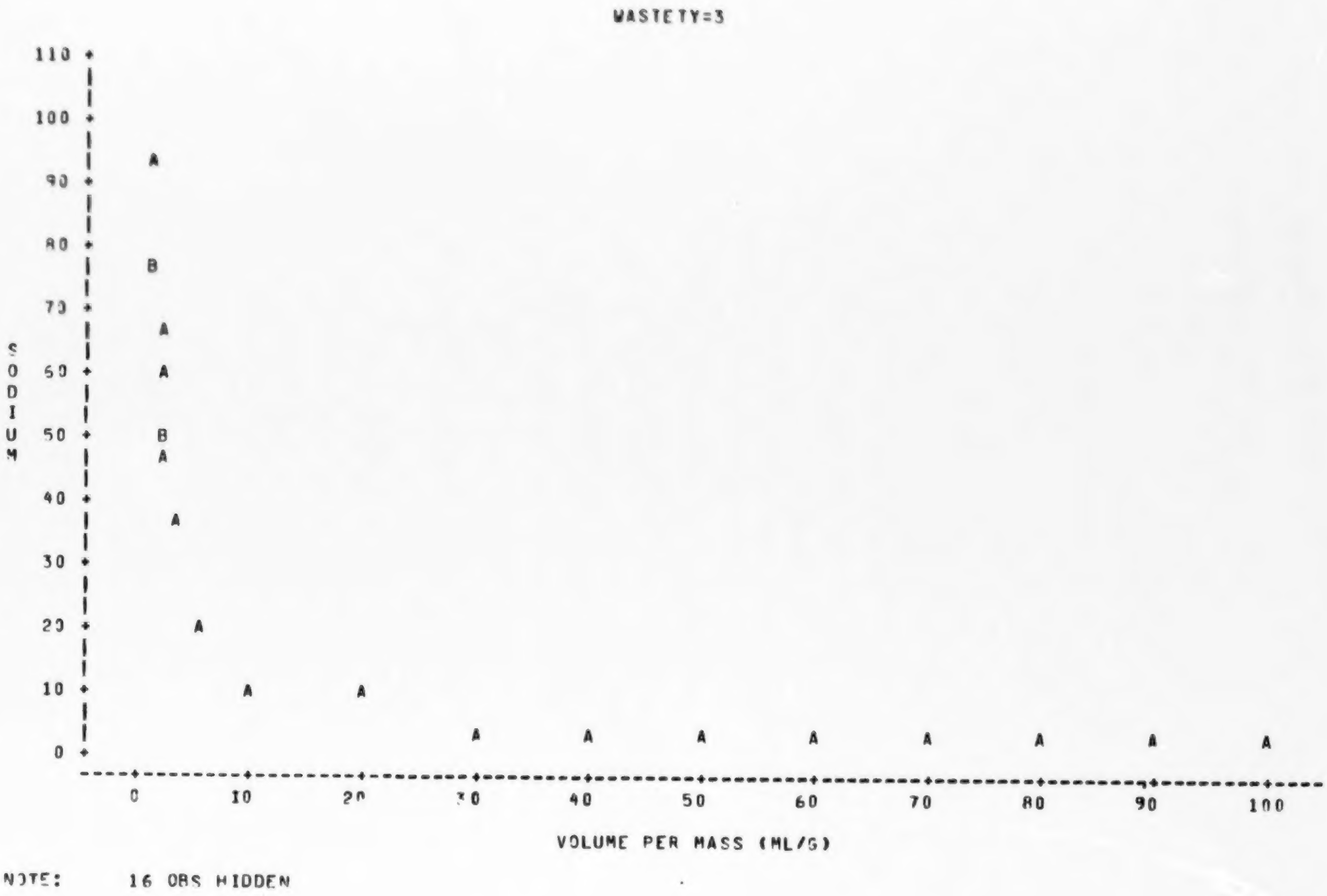
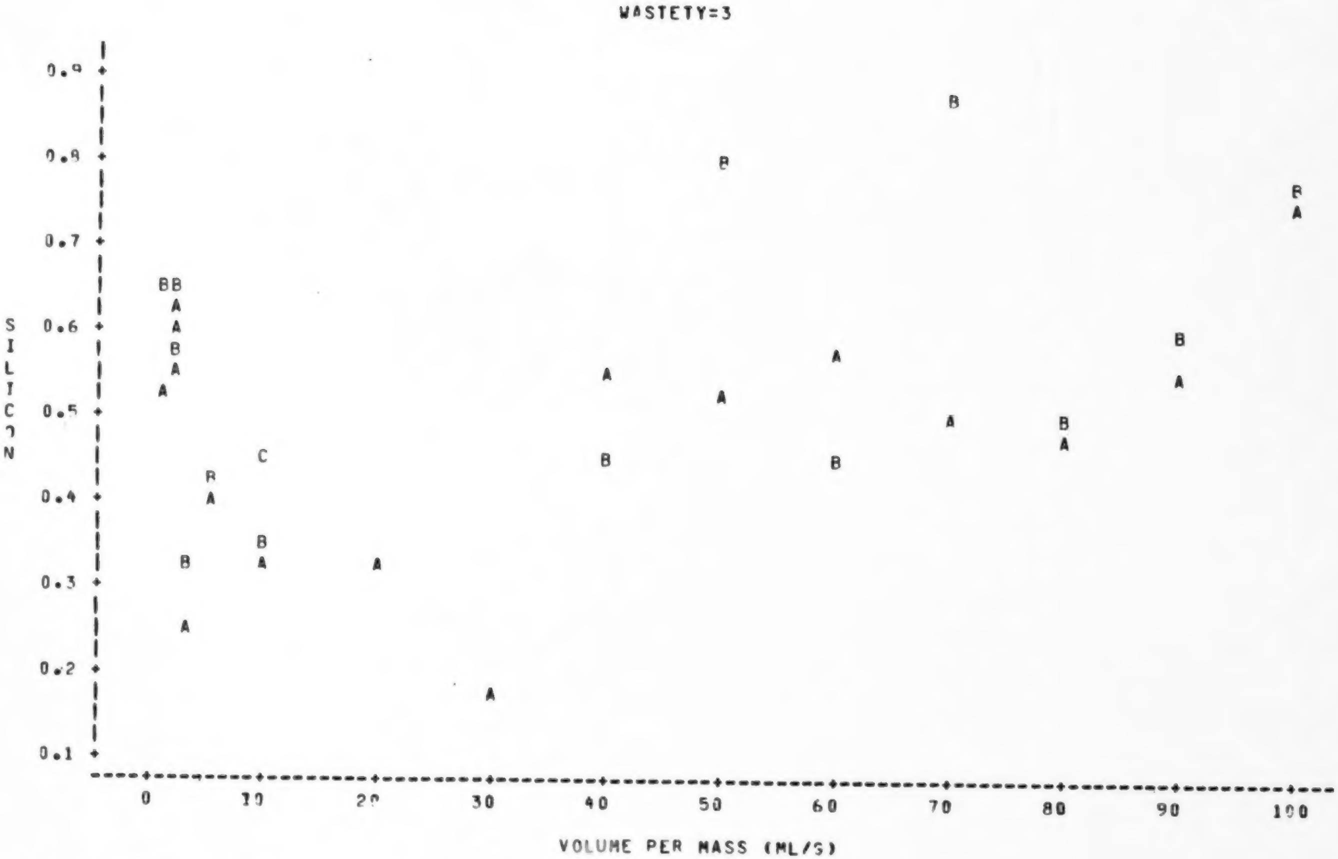


Figure D-24. Concentration of Sodium (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.



NOTE: 4 OBS HIDDEN

Figure D-25. Concentration of Silicon (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.

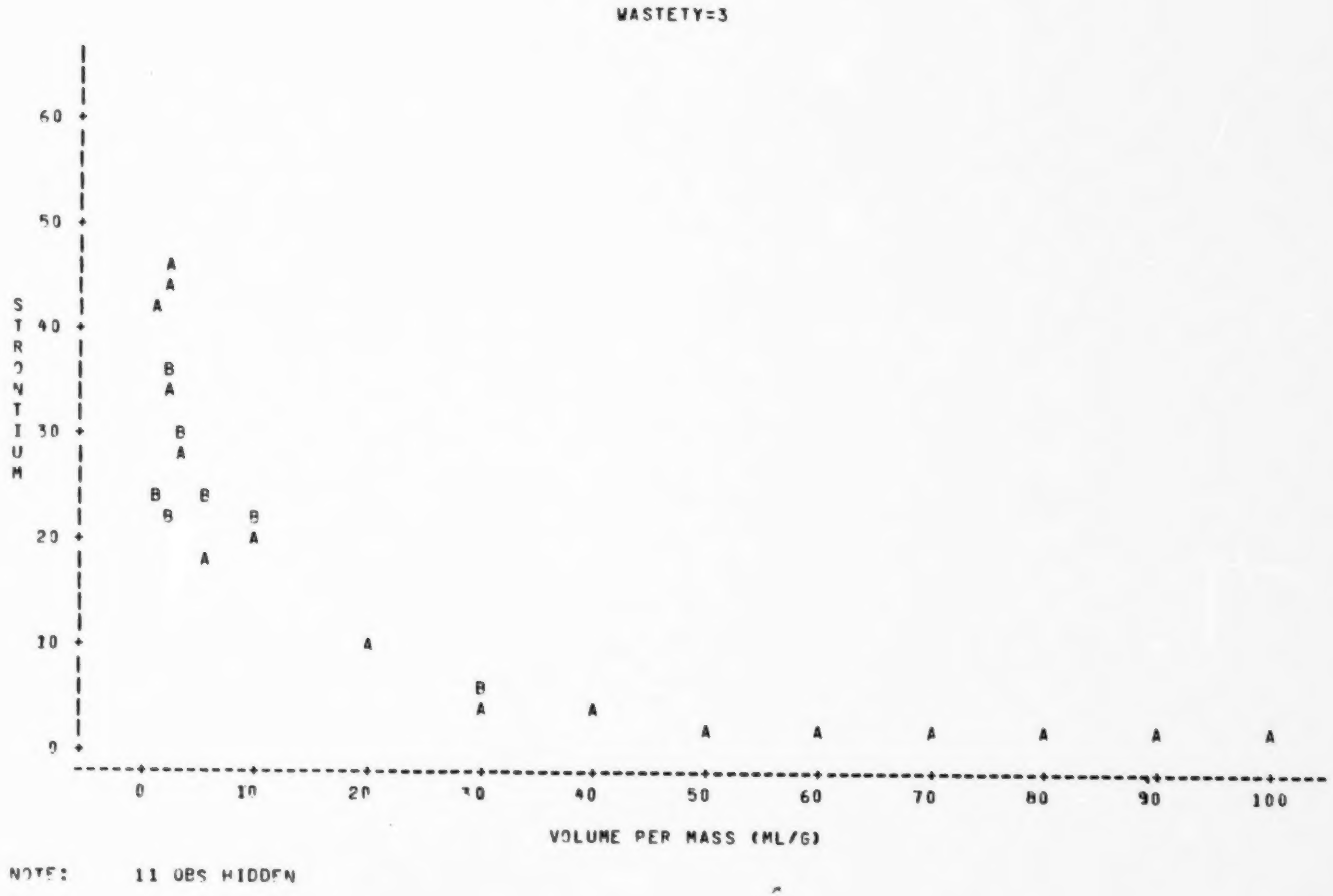
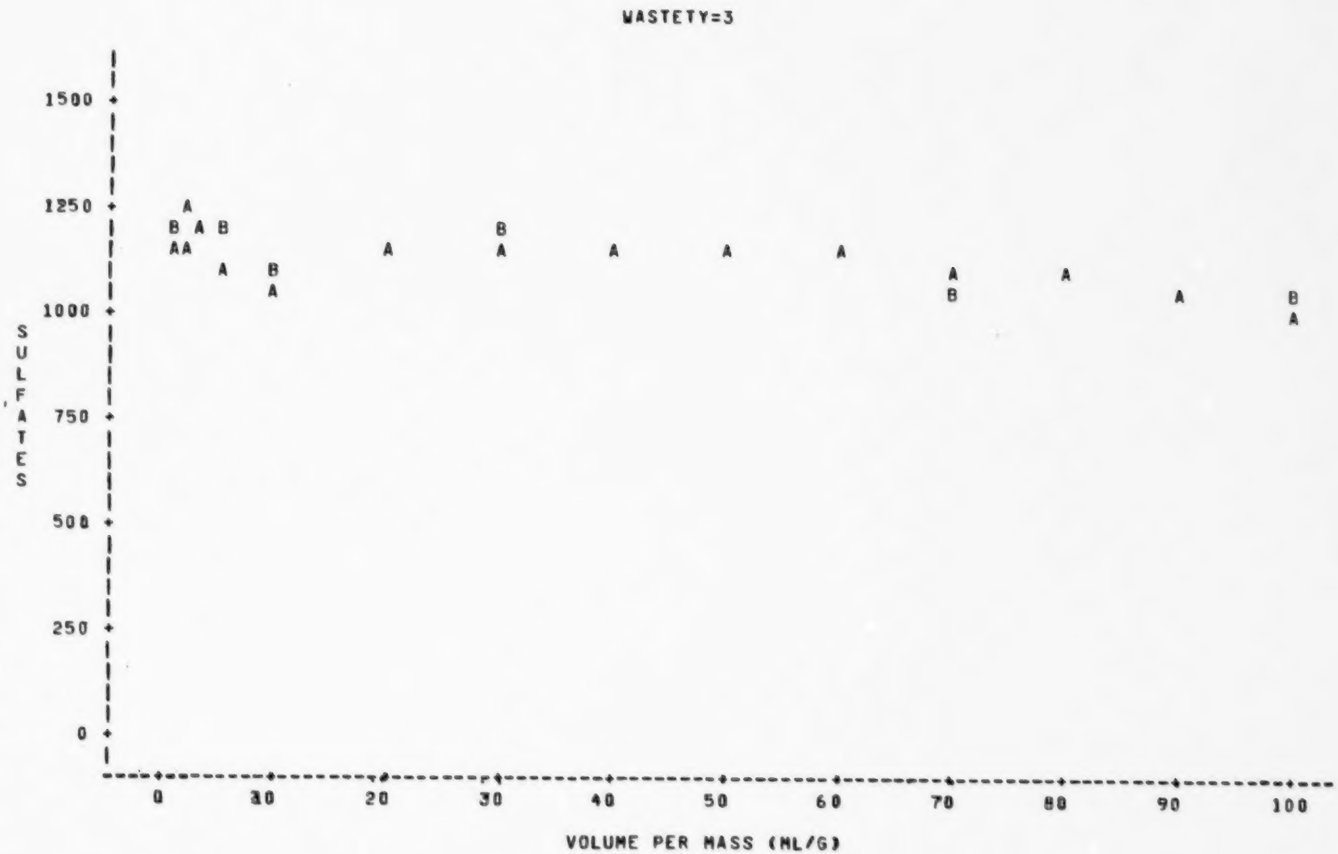
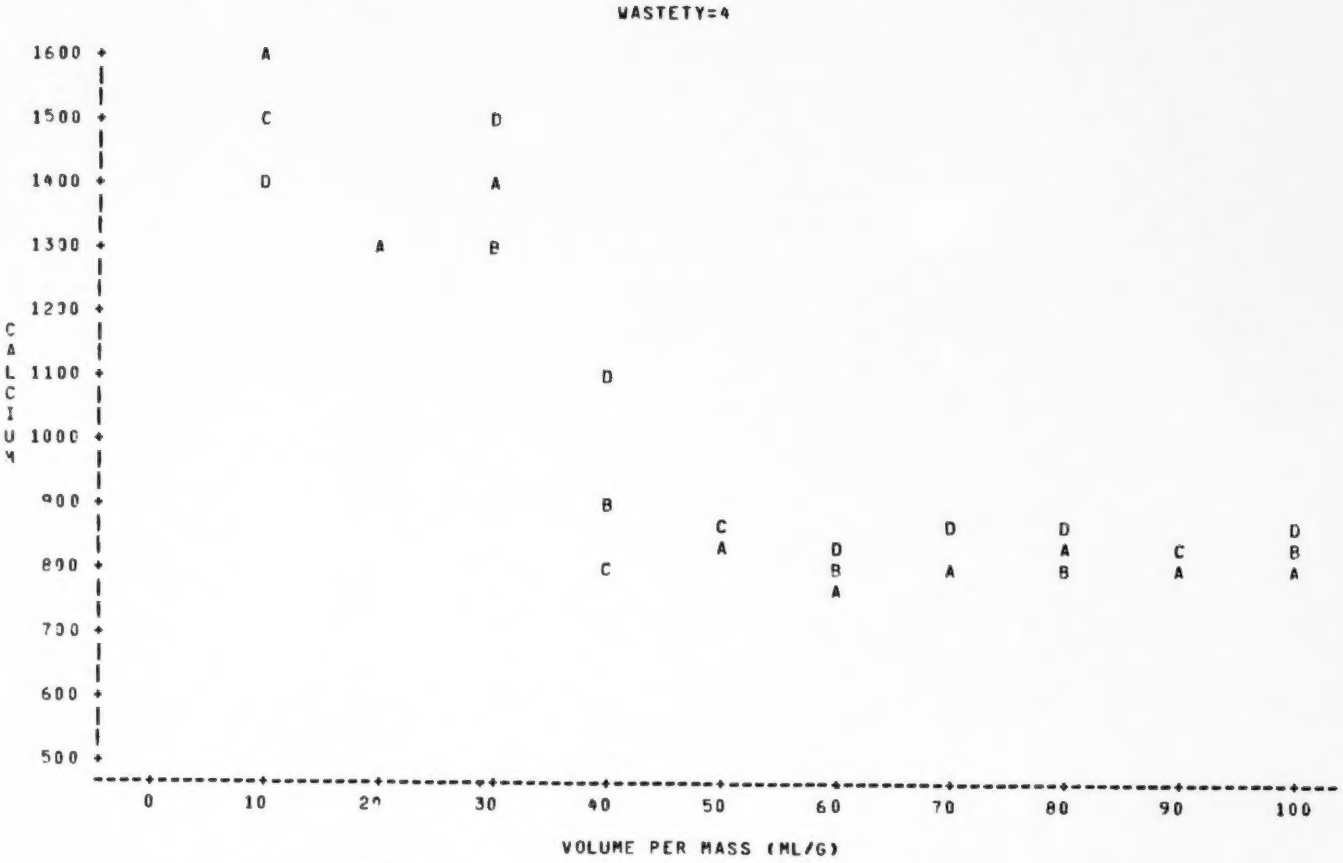


Figure D-26. Concentration of Strontium (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.



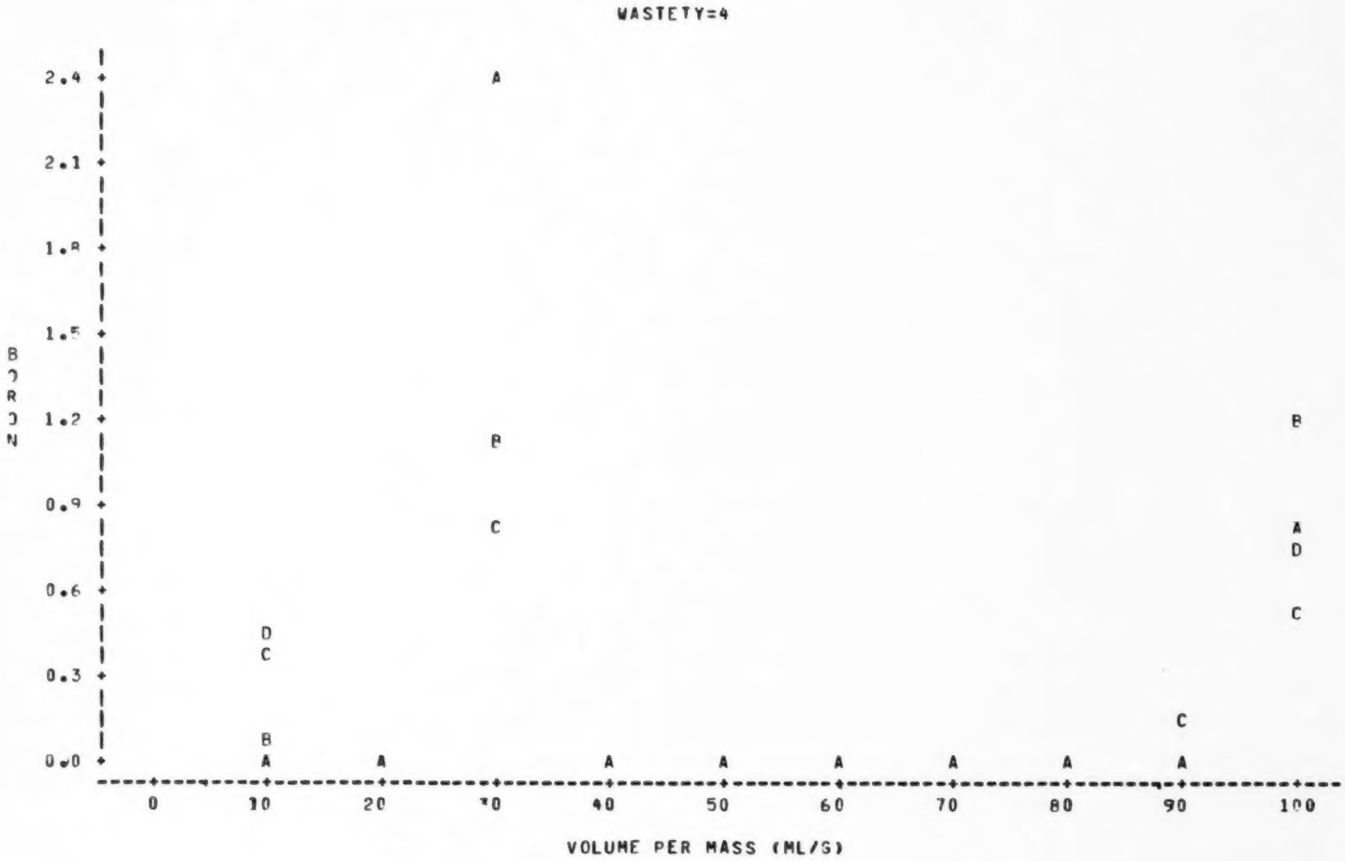
NOTE: 13 OBS HIDDEN

Figure D-27. Concentration of Sulfate (mg/L) as a Function of Volume per Mass (mL/g) for Alliance AFBC Waste Leachate.



NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 14 OBS HIDDEN

Figure D-28. Concentration of Calcium (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.



NOTE: 21 OBS HIDDEN

Figure D-29. Concentration of Boron (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.

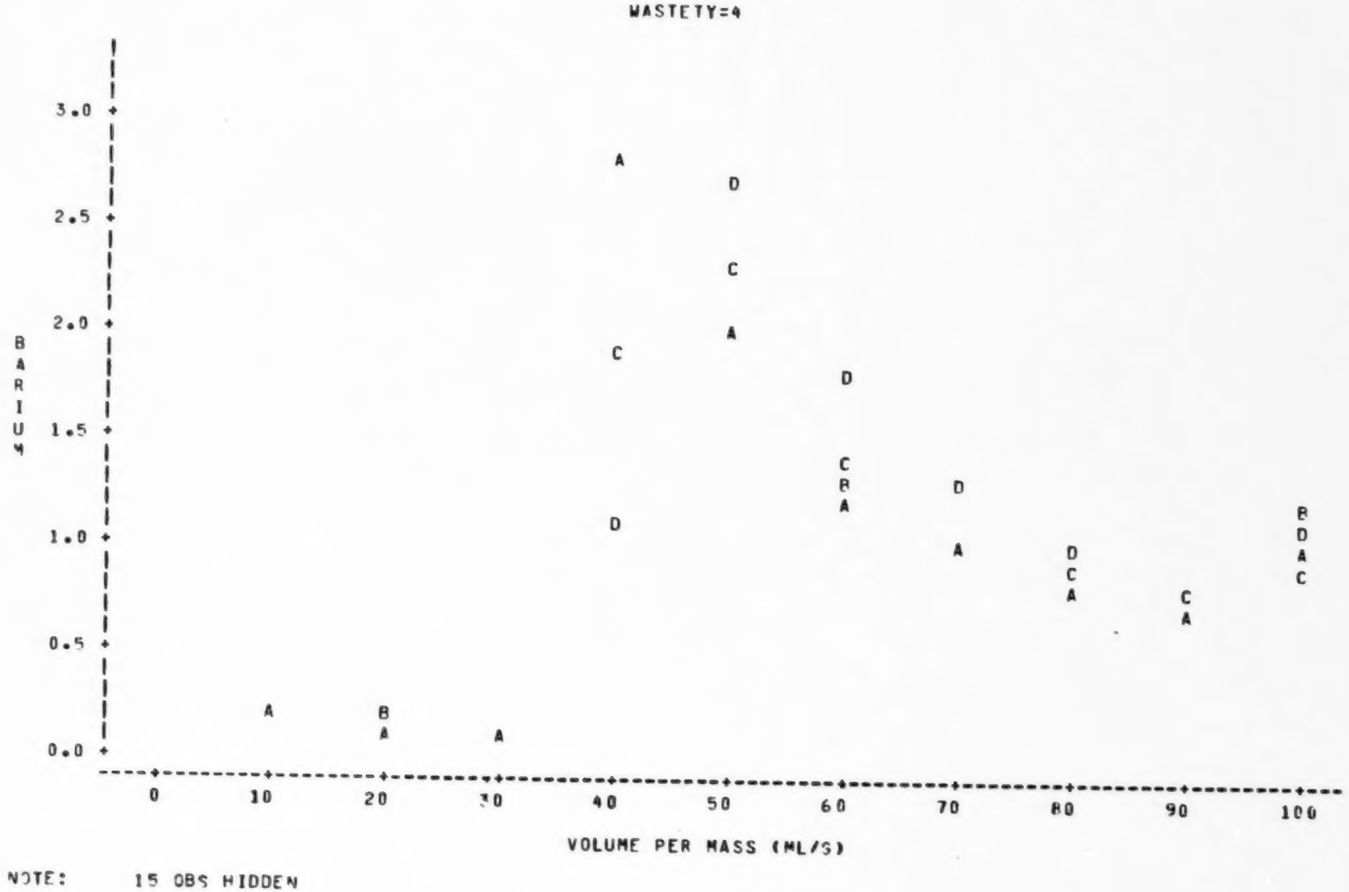
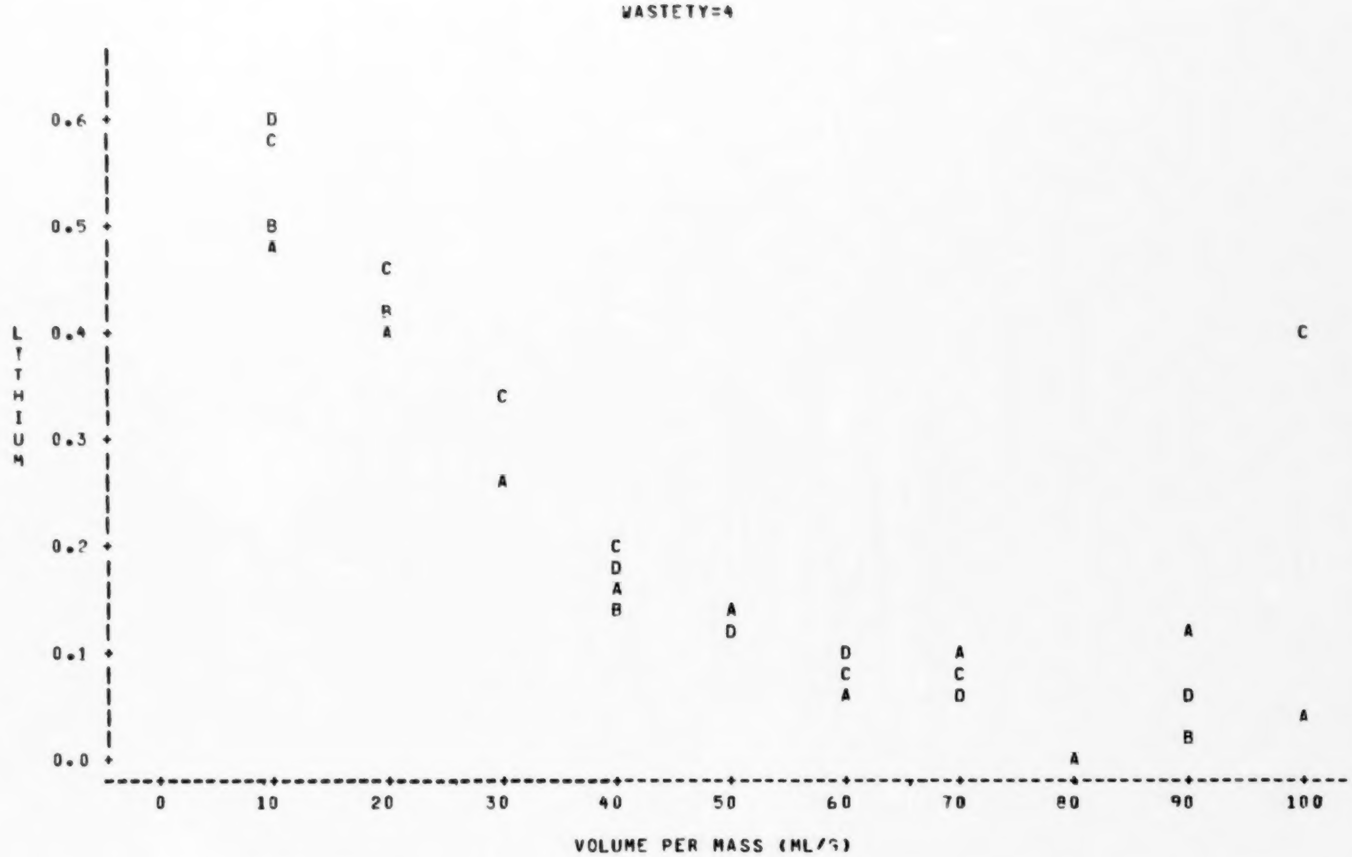


Figure D-30. Concentration of Barium (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.



NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 12 OBS HIDDEN

Figure D-31. Concentration of Lithium (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.

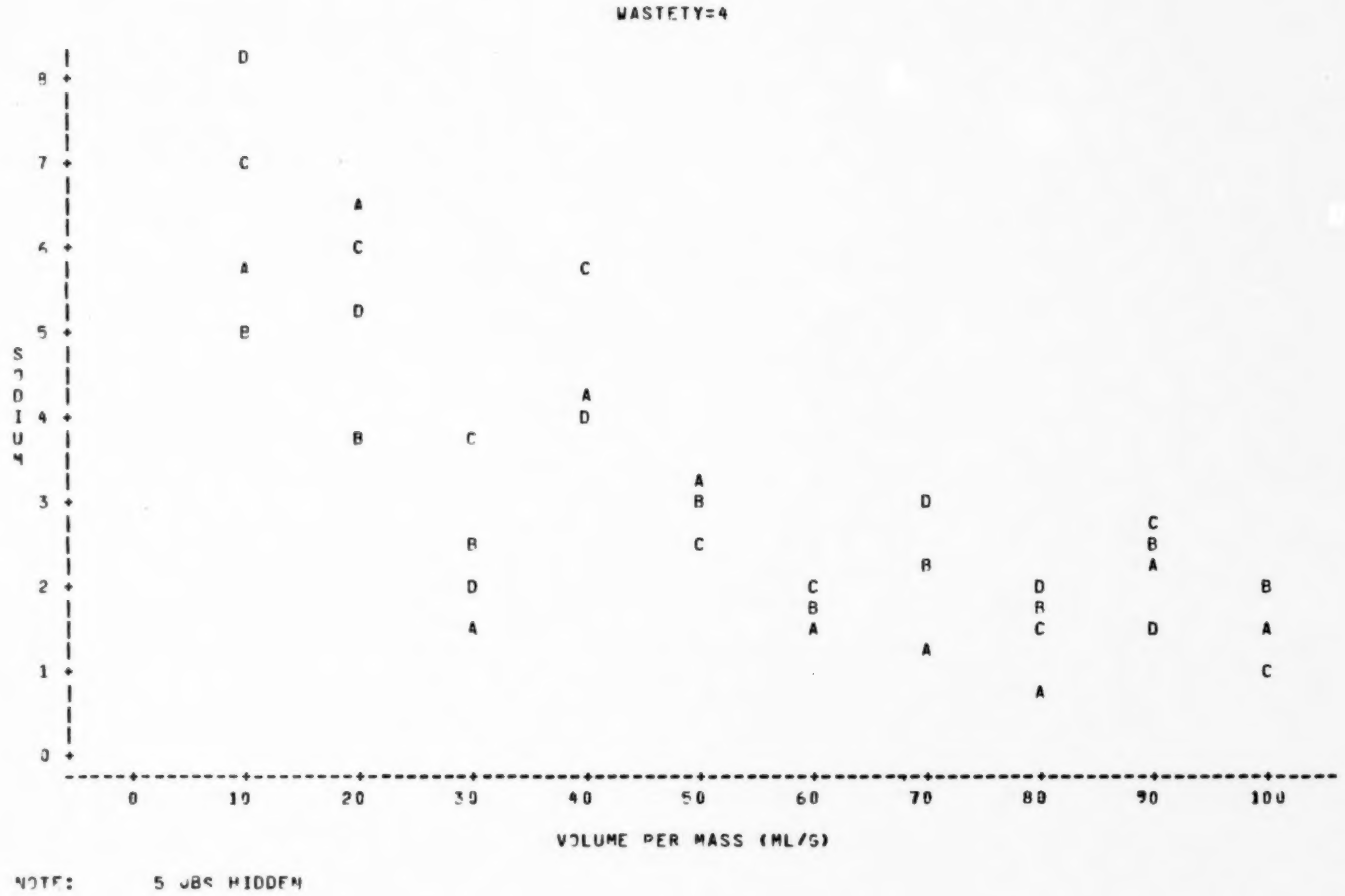


Figure D-32. Concentration of Sodium (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.

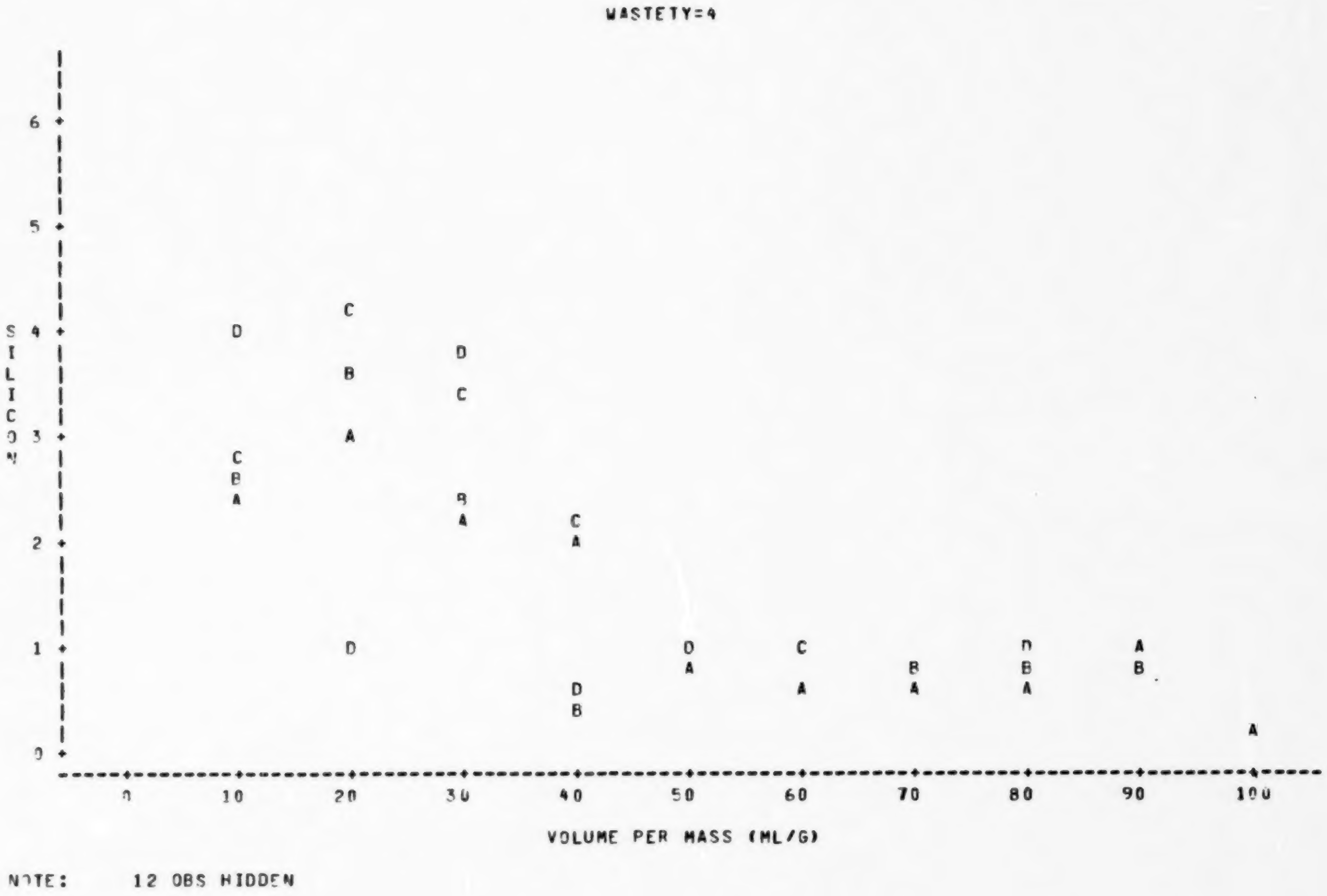


Figure D-33. Concentration of Silicon (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.

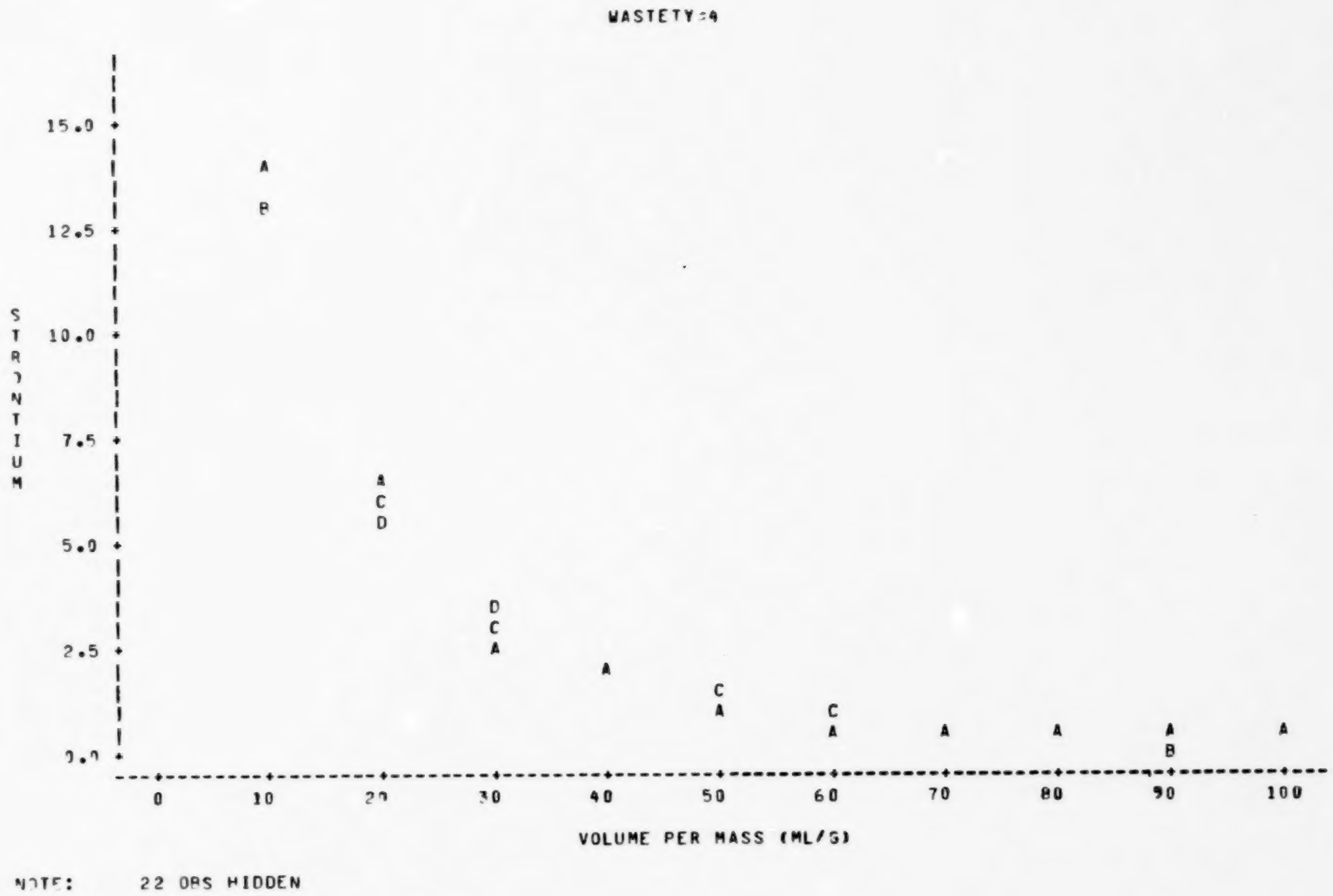


Figure D-34. Concentration of Strontium (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.

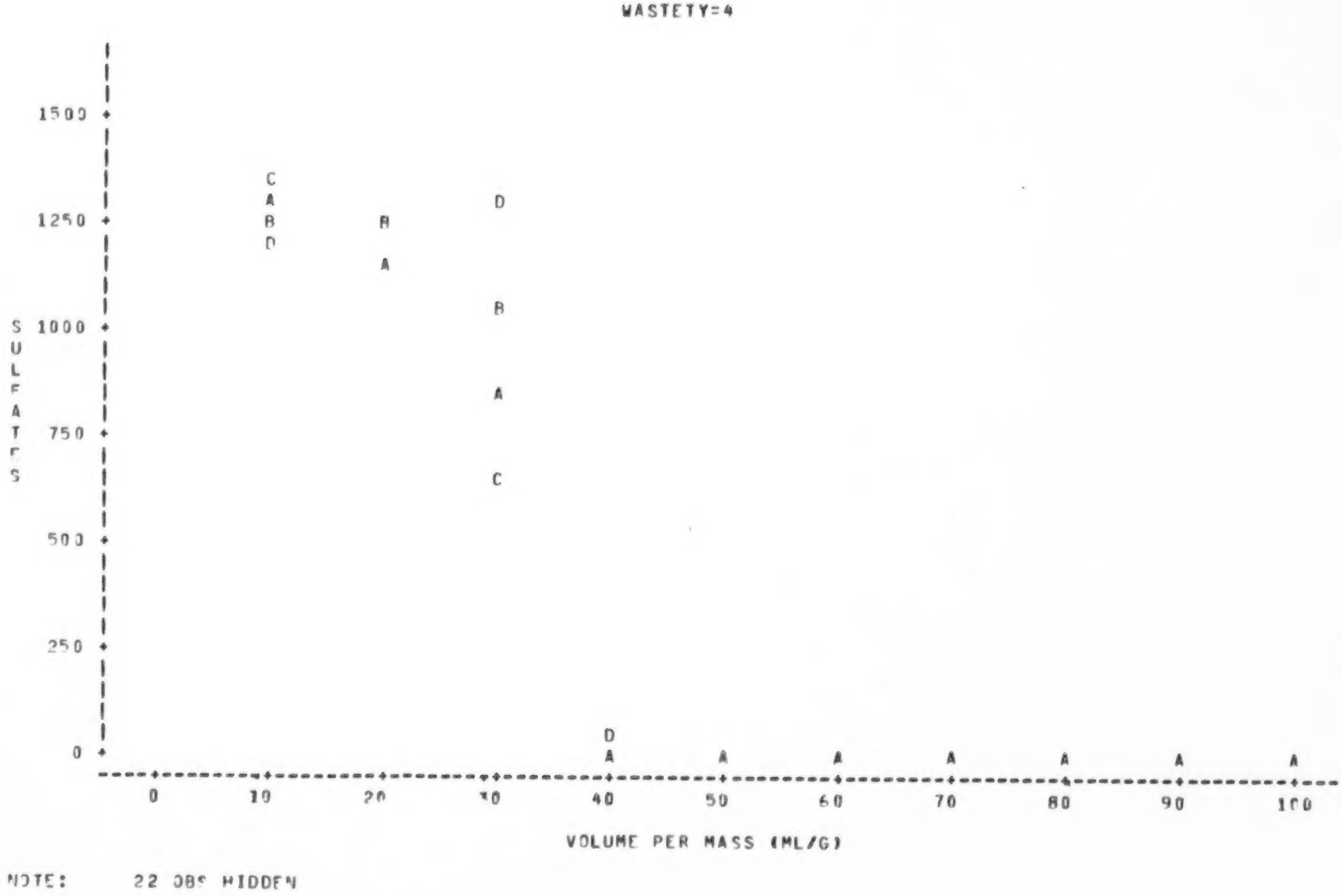


Figure D-35. Concentration of Sulfate (mg/L) as a Function of Volume per Mass (mL/g) for Georgetown AFBC Waste Leachate.

Appendix D

Attachment 2

Figures D-36 to D-47

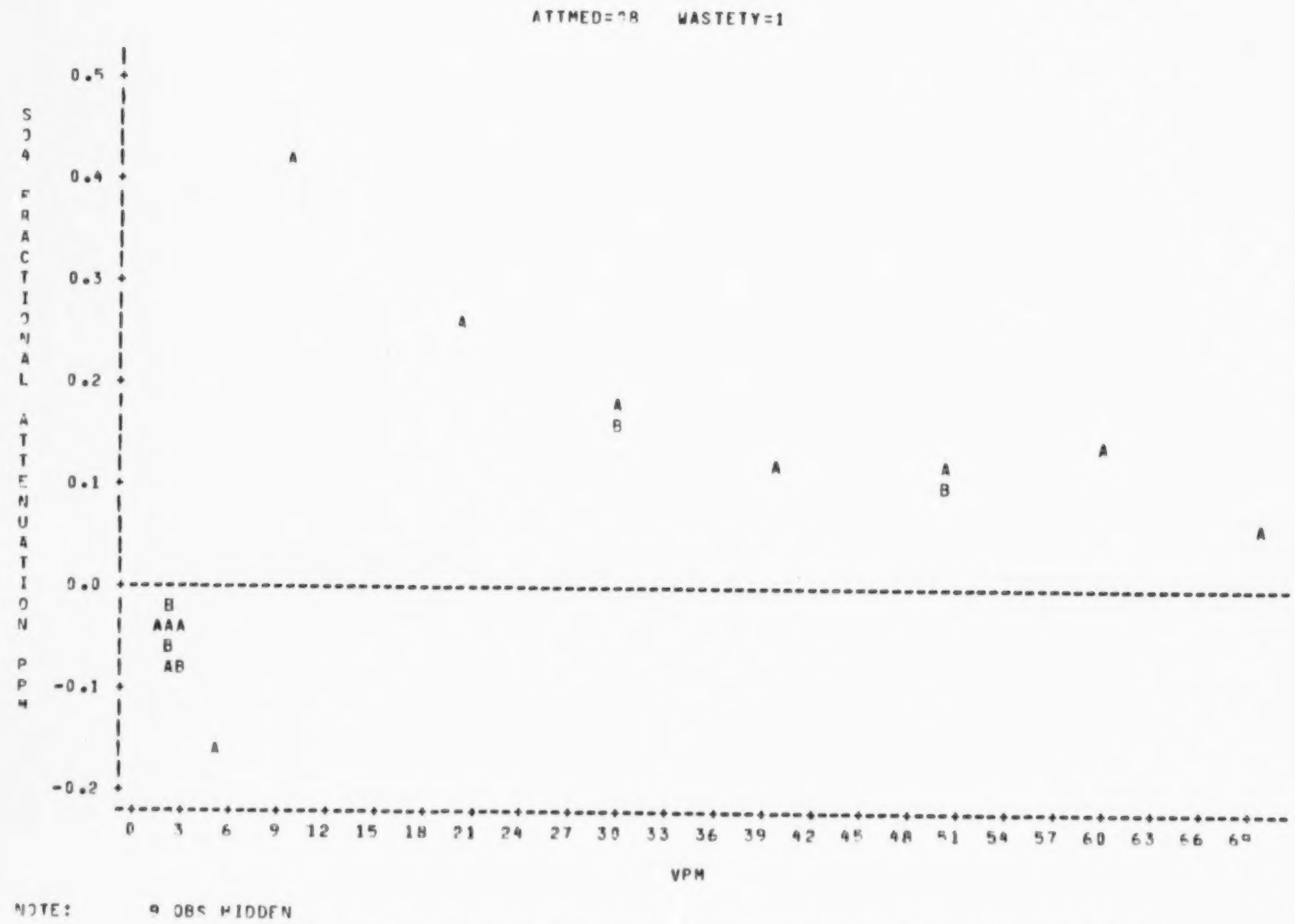
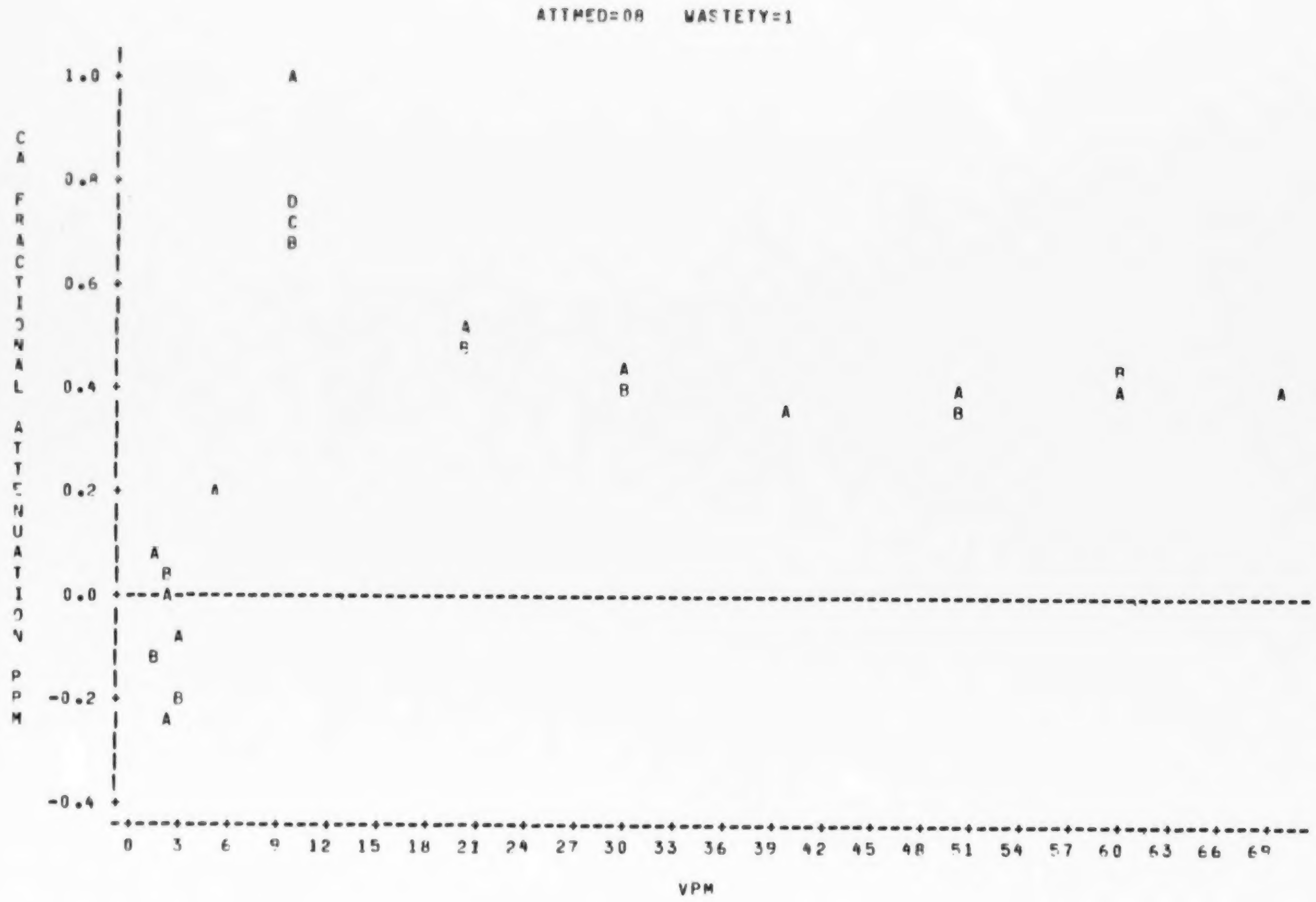
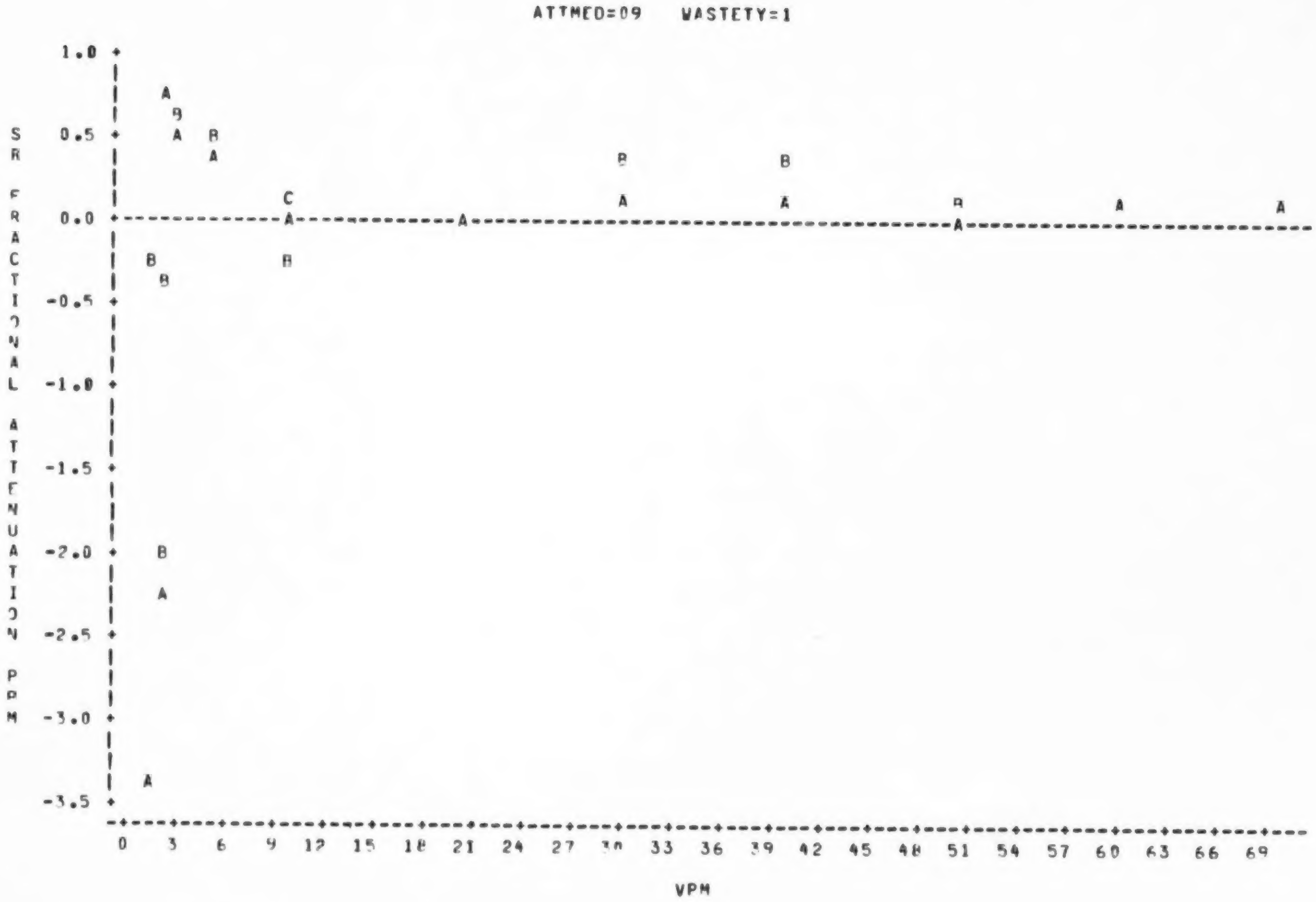


Figure D-36. **Laboratory Fractional Attenuation (A_L) Trends of Sulfate as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.**



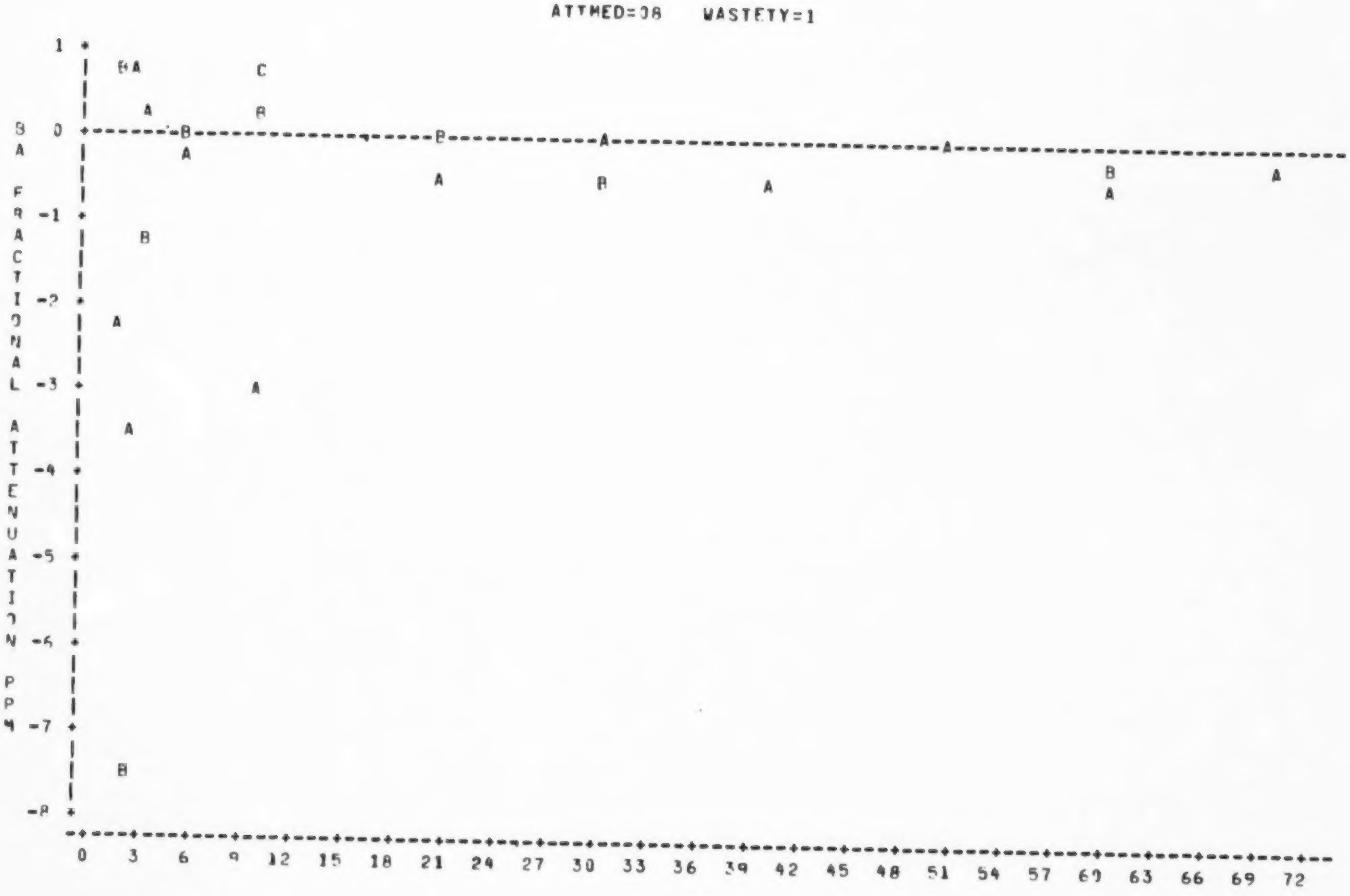
NOTE: 4 OBS HIDDEN

Figure D-37. Laboratory Fractional Attenuation (A_L) Trends of Calcium as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.



NOTE: 4 OBS HIDDEN

Figure D-38. Laboratory Fractional Attenuation (A_L) Trends of Strontium as a Function of Volume Per Mass for PFBC Waste Leachate and Interburden Disposal Medium.



NOTE: 5 OBS HIDDEN

Figure D-39. Laboratory Fractional Attenuation (A_L) Trends of Barium as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.

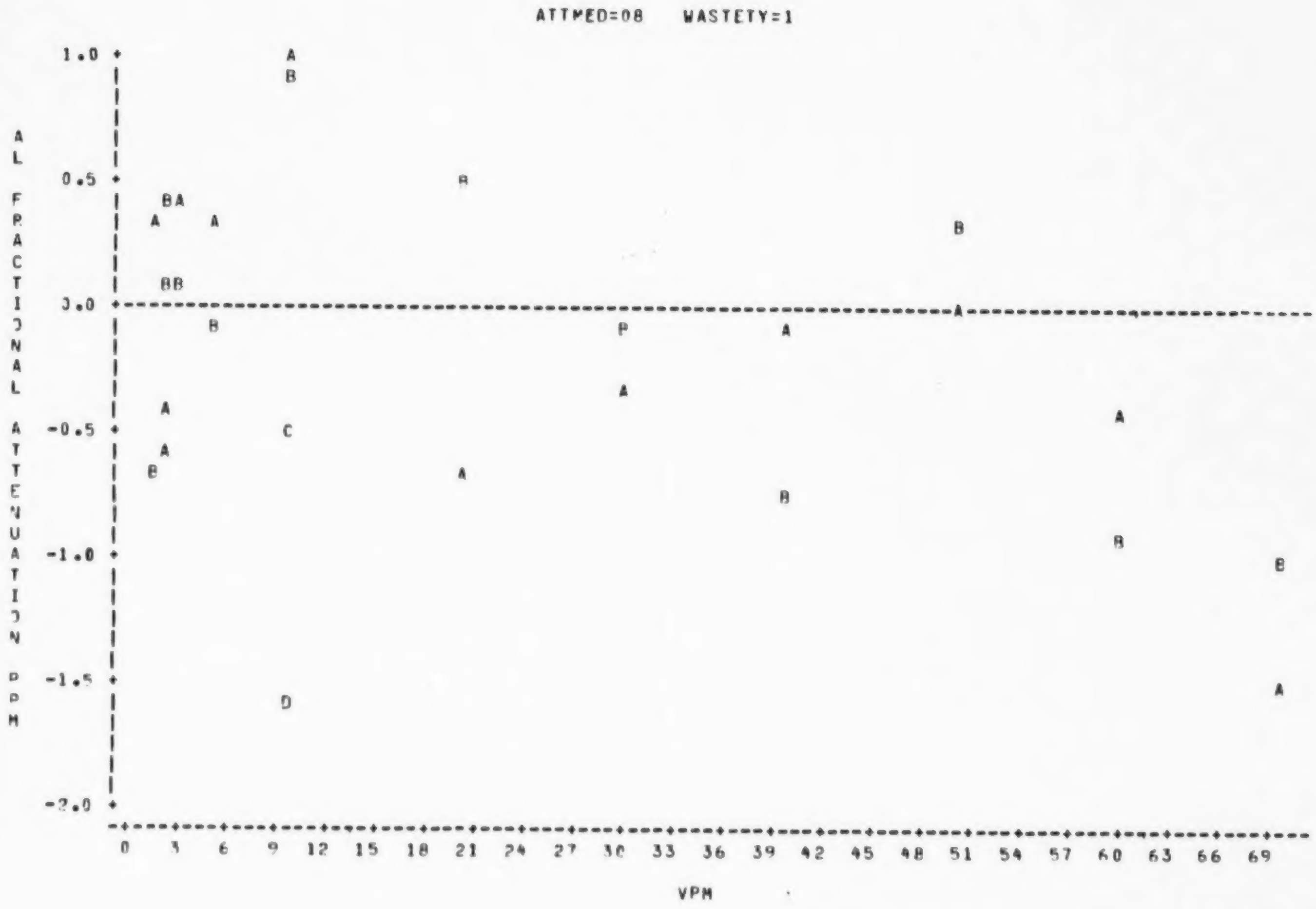
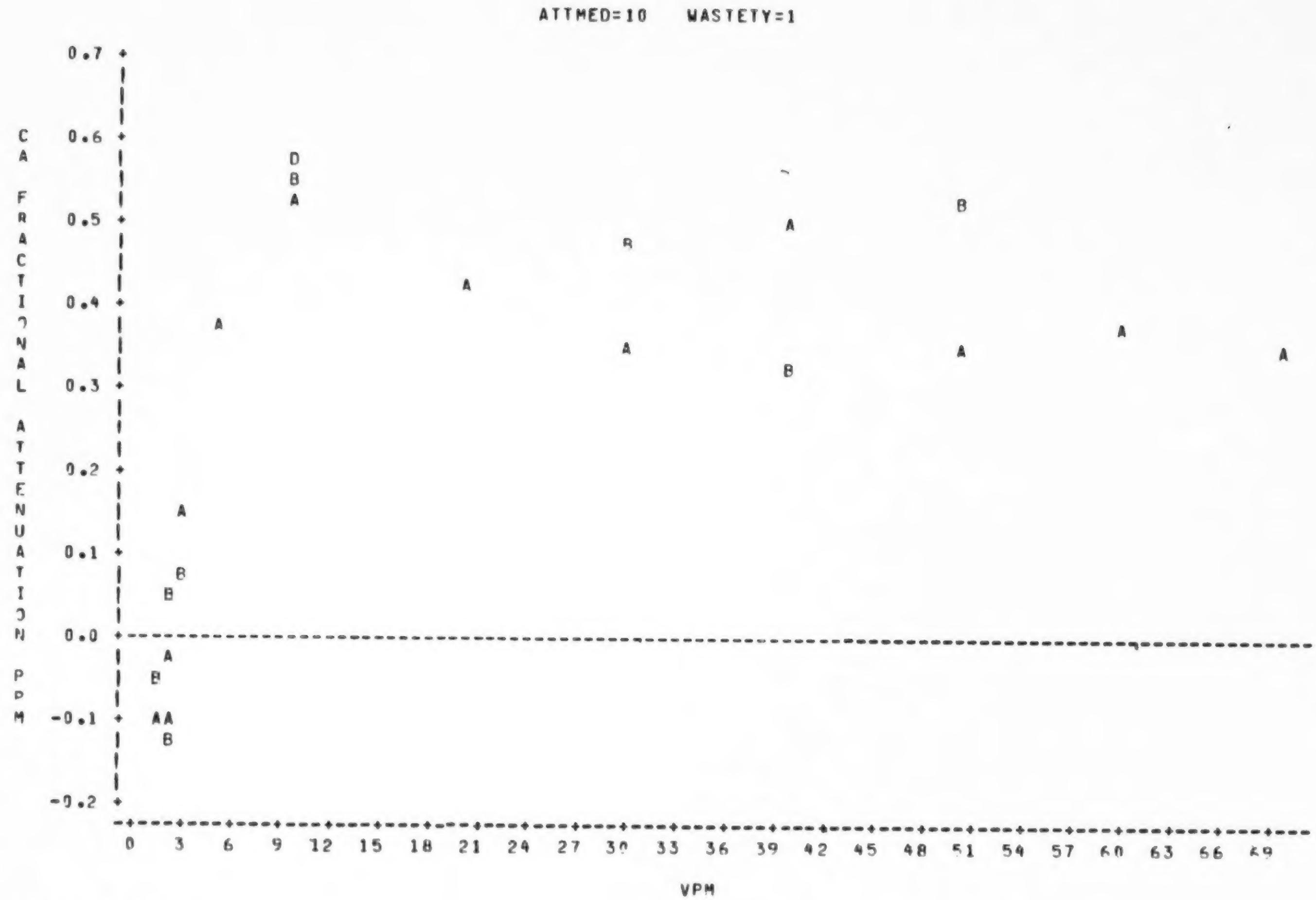
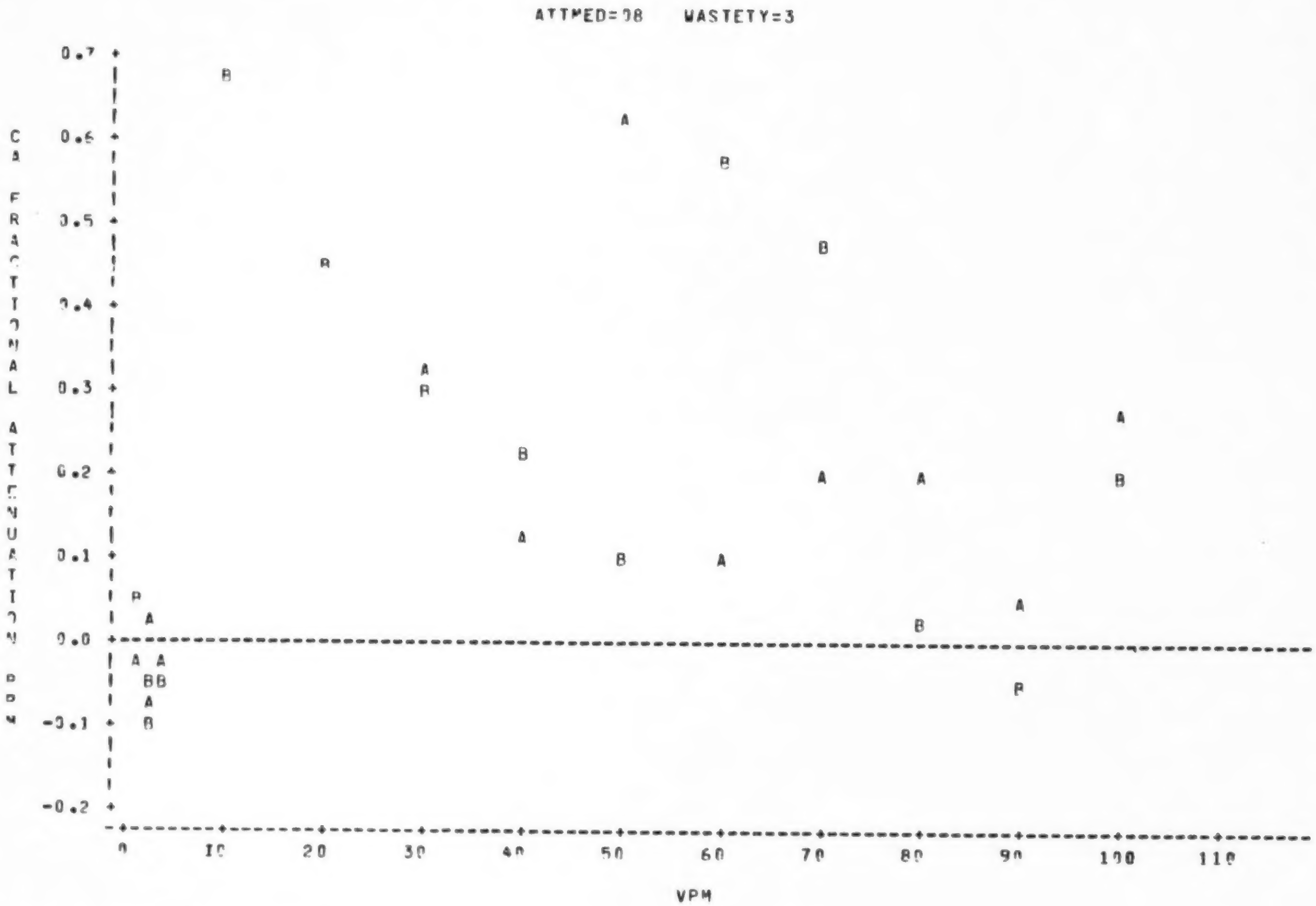


Figure D-40. Laboratory Fractional Attenuation (A_L) Trends of Aluminum as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.



NOTE: 5 OBS HIDDEN

Figure D-41. Laboratory Fractional Attenuation (A_L) Trends of Calcium as a Function of Volume Per Mass for PFBC Waste Leachate and Sandstone Disposal Medium.



NOTE: 6 OBS HAD MISSING VALUES

Figure D-42. Laboratory Fractional Attenuation (A_L) Trends of Calcium as a Function of Volume Per Mass for AFBC Waste Leachate and Shale Disposal Medium.

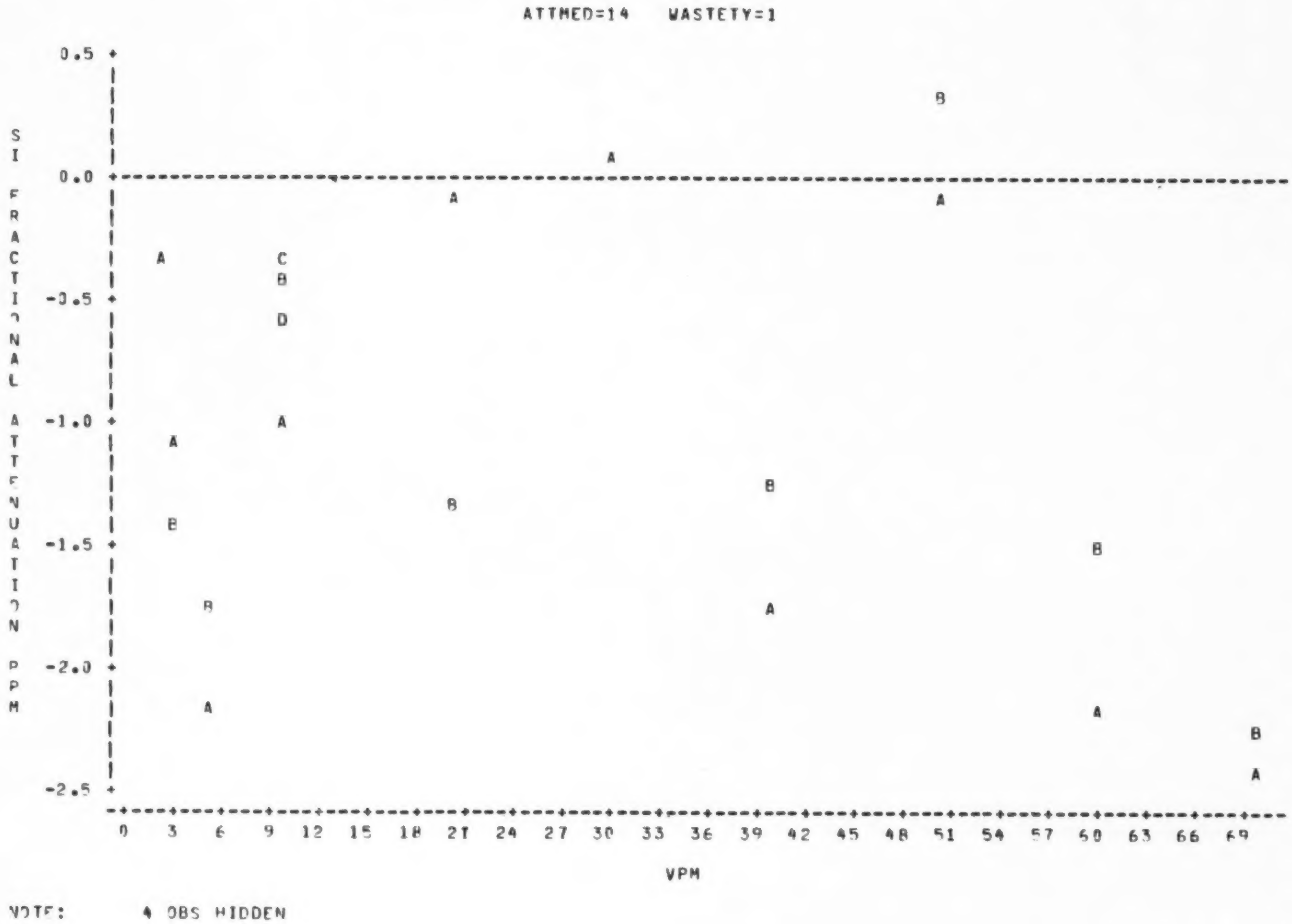


Figure D-43. Laboratory Fractional Attenuation (A_L) Trends of Silicon as a Function of Volume Per Mass for PFBC Waste Leachate and Limestone Disposal Medium.

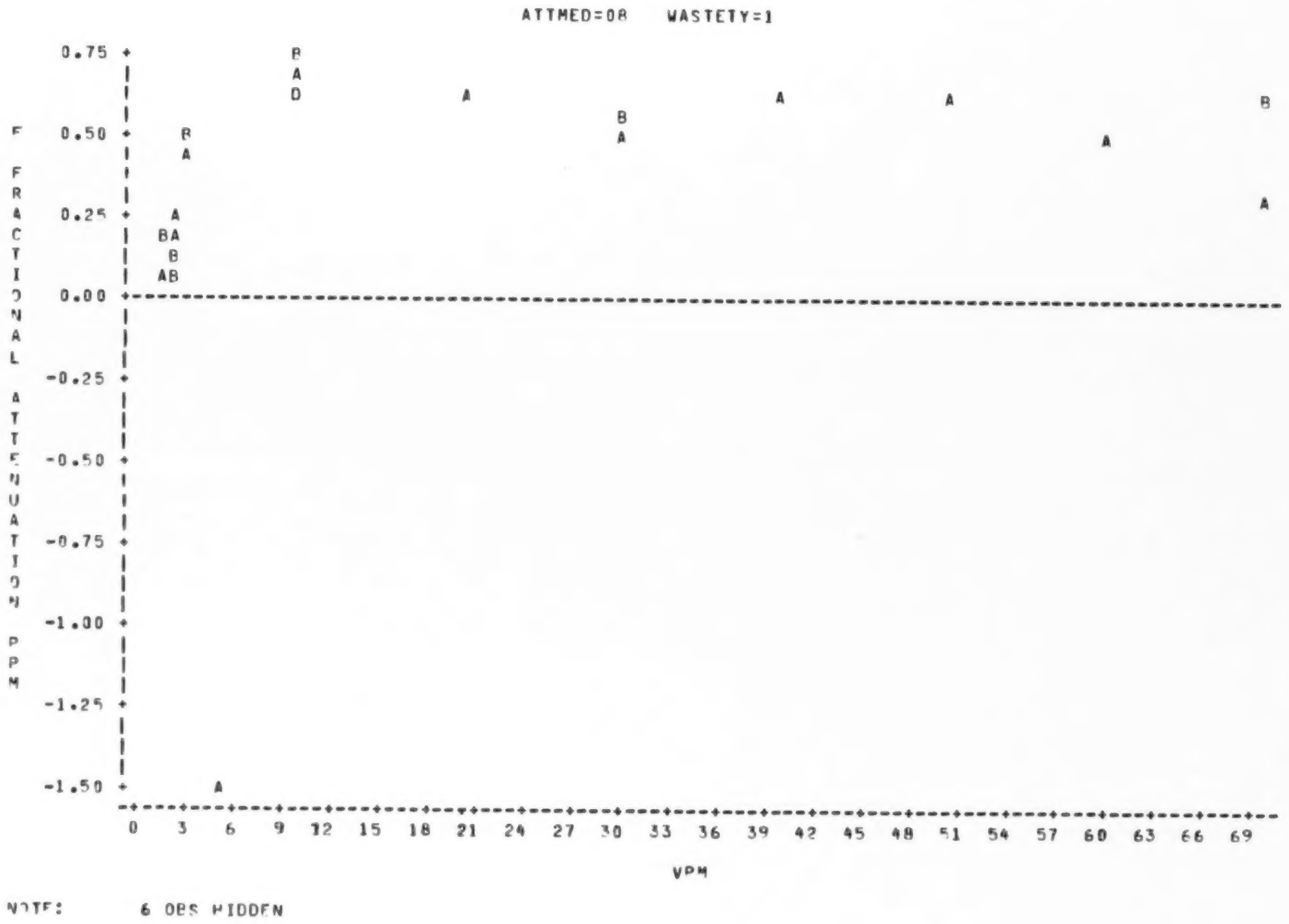


Figure D-44. Laboratory Fractional Attenuation (A_L) Trends of Fluoride as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.

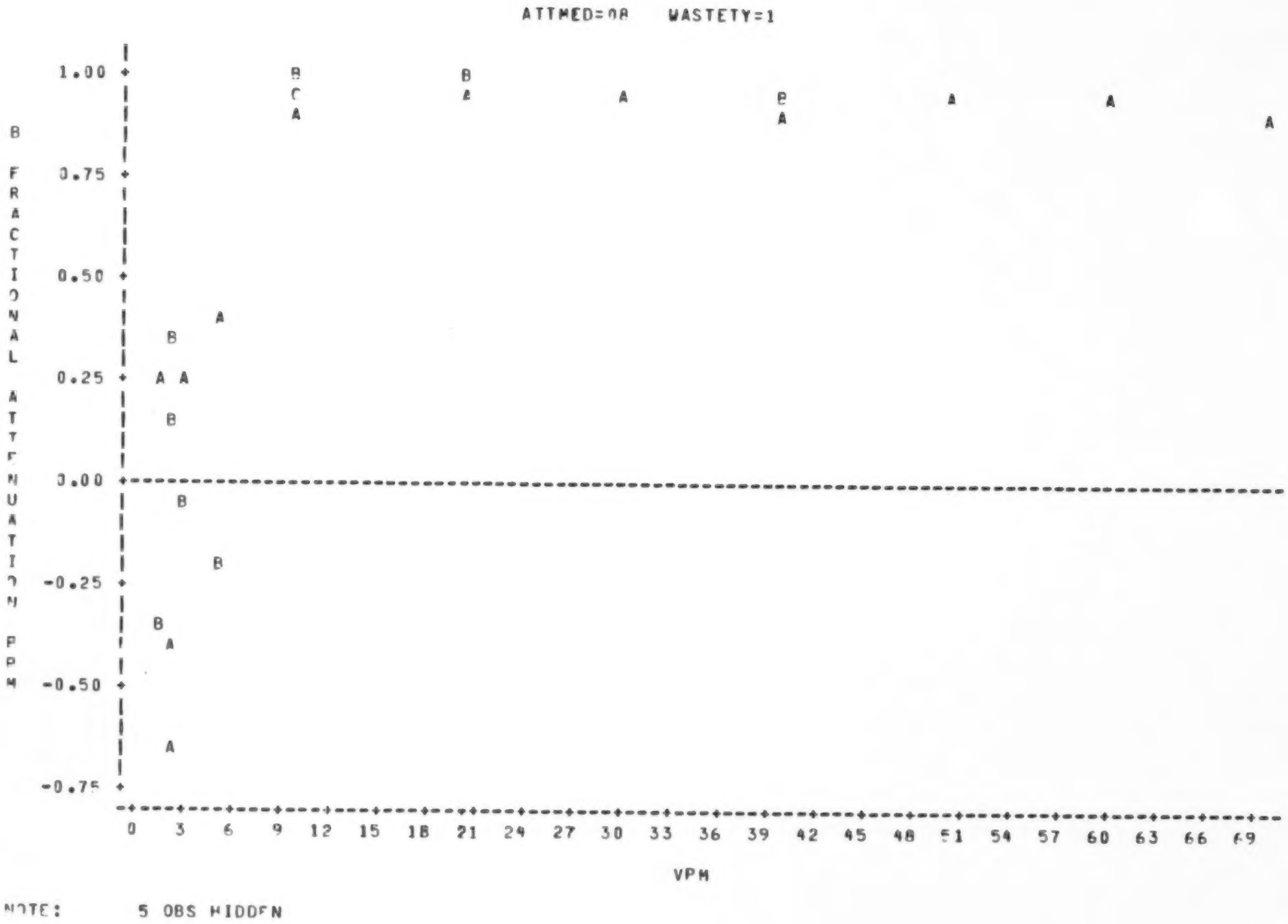
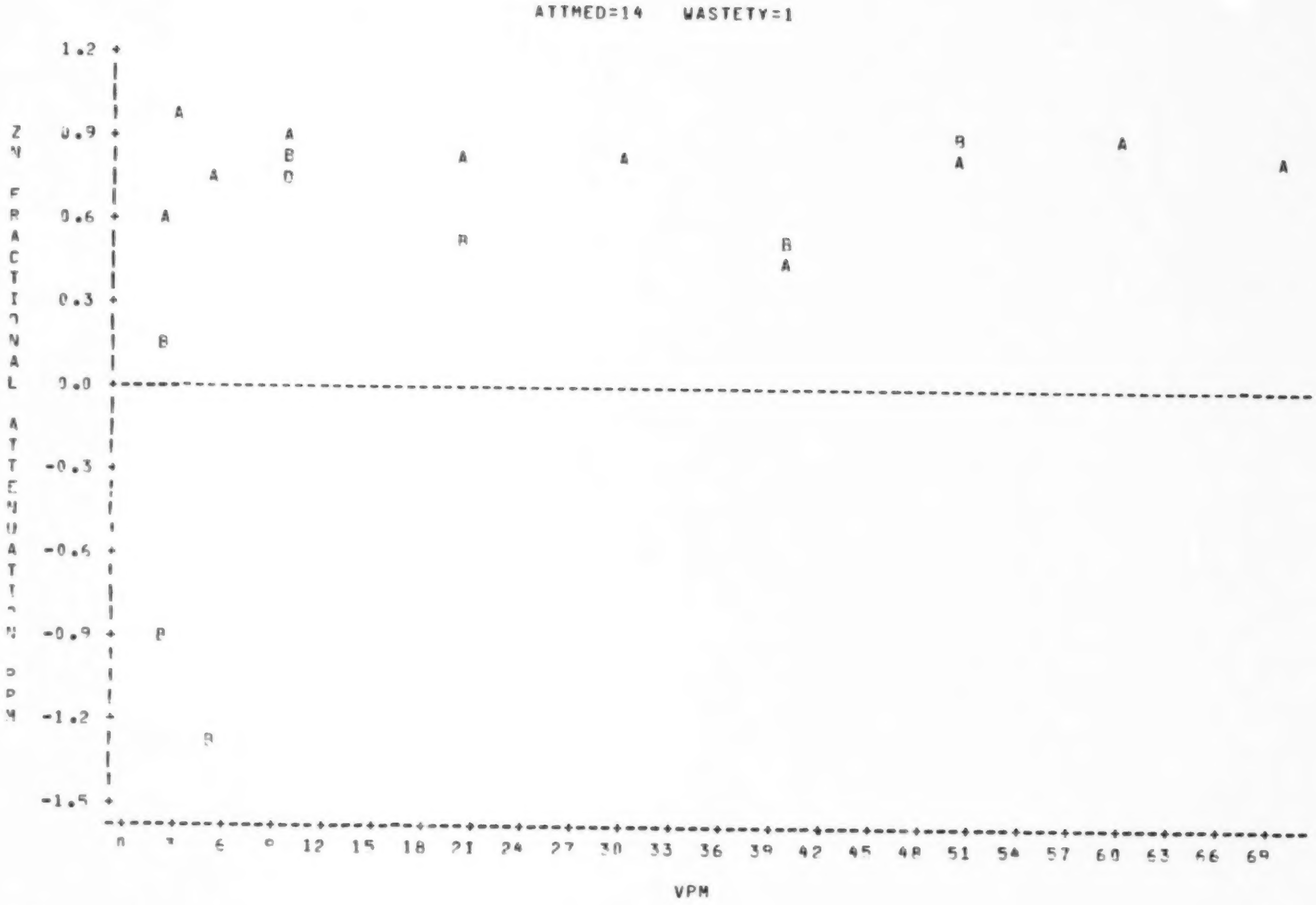
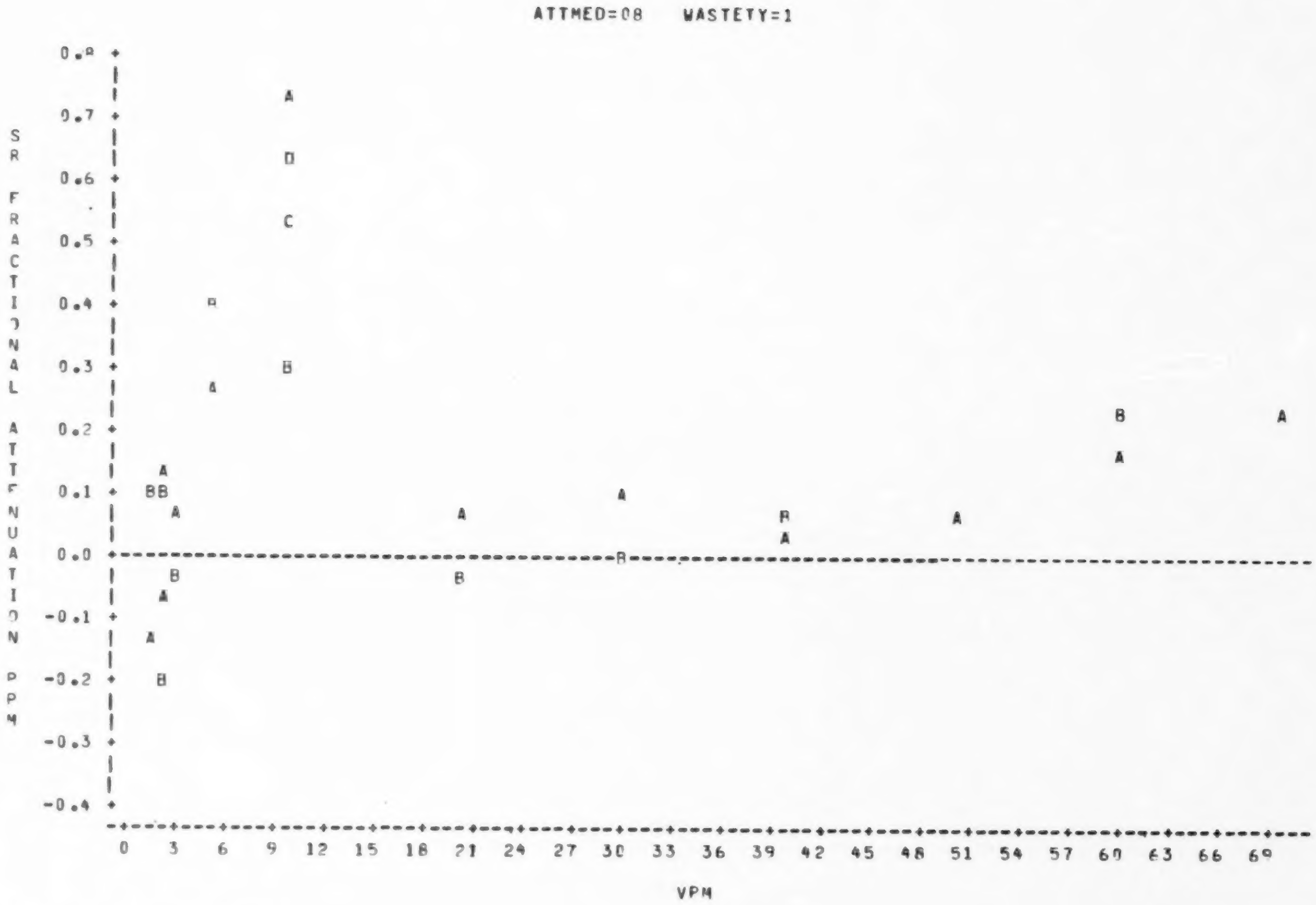


Figure D-45. Laboratory Fractional Attenuation (A_L) Trends of Boron as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.



NOTE: 1 OBS HAD MISSING VALUES 5 OBS HIDDEN

Figure D-46. Laboratory Fractional Attenuation (A_L) Trends of Zinc as a Function of Volume Per Mass for PFBC Waste Leachate and Limestone Disposal Medium.



NOTE: 2 OBS HIDDEN

Figure D-47. Laboratory Fractional Attenuation (A_L) Trends of Strontium as a Function of Volume Per Mass for PFBC Waste Leachate and Shale Disposal Medium.

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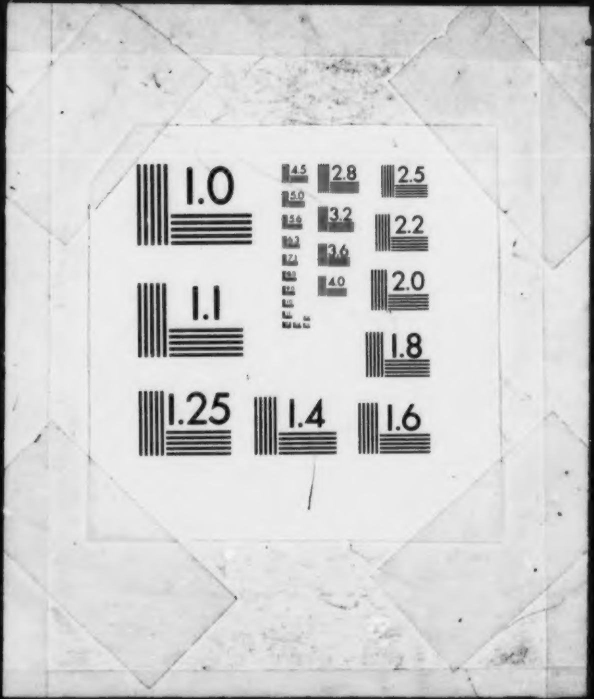
PB 85

175 883


1.0
4.5
5.0
5.6
6.3
7.1
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

Appendix E

BEHAVIOR OF FBC WASTES UNDER FIELD CONDITIONS

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E.1 Overview

Thirteen hydrologically isolated field cells were constructed and operated in order to observe behavior of FBC wastes in a variety of disposal environments under field conditions. The goal of this effort was to observe the generation and attenuation of leachate from various combinations of FBC wastes and disposal media. The field cells were large-diameter, disturbed-media lysimeters which simulated FBC landfills as closely as practicable. The field cells were designed as a logical bridge between laboratory batch equilibration tests and a full scale, operating disposal facility. The major phenomena simulated (i.e., differences from laboratory conditions) were unsaturated flow, intermittent input from natural rainfall, temperature fluctuation, and availability of atmospheric CO_2. The product of the field cell test phase was a series of observations (throughput volumes, chemical analyses of leachate samples) over time, reflecting the effects of a natural climatic pattern on representative FBC waste disposal systems.

All field investigations were performed at the former EPA Mine Drainage Control Facility at Crown, West Virginia (about nine miles southwest of Morgantown). Six disposal media samples were obtained from the region around the field site. Each of the disposal media types was used in at least one of the field cells. The field cells were constructed as large (four-foot diameter, eight-foot long) cylindrical lysimeters which were installed below the ground surface. Cells containing Exxon PFBC waste, Alliance AFBC waste, and disposal media only were installed. Each waste-bearing cell was designed to simulate actual landfill conditions and was constructed with an upper foot of disposal medium underlain by 18 inches of FBC waste. Below the waste layer was a three-foot layer of disposal medium. The cells contained an upper sampling point below the waste layer to allow leachate to be collected after generation. A second sampling point below the lower disposal medium layer allowed leachate to be collected after exposure to the media so that an assessment could be made of the attenuation of the leachate. The cells containing disposal media only had just one sampling point at the bottom of the cells. All field cells were maintained in unsaturated conditions. The cells containing Exxon PFBC waste were operated for about 23 months, and the Alliance AFBC cells were operated for about 20 months.

A hydrologic balance computation was performed for each of the field cells. Most of the losses from the cells is attributed to evaporation, inasmuch as the cells were operated in hydrologic isolation from the subsurface environment. The average losses were about 44 percent from the Exxon PFBC cells and about 61 percent for the Alliance AFBC cells. The annual equivalent of the evaporative losses is somewhat higher than the evaporation rate recorded at the nearest U.S. Weather Station at Clarksburg, West Virginia.

For the six Exxon PFBC field cells, the initial concentrations of major species in leachates from the upper sample points were quite high and then decreased to lower levels and remained relatively stable. Sodium, potassium, and sulfate in particular had high initial values. So also did B, Cl, Cr, Cu, Mg, Mo, TDS and specific conductance for most field cells. Calcium, on the other hand, had initially low values and increased substantially with time.

The Alliance AFBC field cells did not exhibit similar initially high concentrations of most species from the upper sample point. Aluminum, chromium, copper, and pH were generally higher initially than in the later stages of operation, but other species had relatively constant concentrations throughout the period of operation.

Because of the differences observed in the initial behavior of leachate from the upper sample points of the PFBC and the AFBC field cells, another comparison was made on the basis of concentration ranges observed after 30 days or more of operation. This comparison showed that the concentration ranges were similar for the set of Exxon PFBC cells and Alliance AFBC cells; variation was generally as great within each set as between the sets. The pH values were generally much lower throughout the period of operation in the PFBC cells than in the AFBC cells.

A similar comparison was made between the field cells containing waste (upper sample point) and the cells containing disposal media only (both field control cells and lab control columns). This comparison showed that the concentrations of the heavy metals were comparable for the cells containing wastes and the cells containing media only (with the exception of the cells containing mine interburden, which had much higher levels of heavy metals). The concentrations of calcium and sulfate were higher in leachate from sandstone and shale disposal media than in AFBC waste leachate but were comparable to PFBC leachate concentrations. Leachates from cells containing waste were generally higher in Cl, B, Li, K, Na, and Sr than leachates from cells containing disposal media.

The concentrations of leachates from the lower sampling points of the field cells were used to assess the attenuation of leachate by the lower layer of disposal medium. A derived parameter, fractional attenuation (A_F), was also used to evaluate attentuation by the lower layer.

For the Exxon PFBC field cells, the initial high concentrations of several species observed for the upper sample point were not seen for the lower sample points. In general, A_F values were highly variable for the species analyzed when the entire period of performance was considered. A separate evaluation of leachate analysis data for samples collected after 60 days of operation was also performed. This evaluation showed good agreement of results from the two replicate Exxon PFBC field cells (both containing shale) for 13 species. For six species, the A_F values had opposite signs for the replicate cells, indicating that the species were attenuated in one cell and mobilized in the other. A comparison among the six PFBC field cells showed that boron and silicon were attenuated in all cells and

Al, Mg, Ti, and V were mobilized in all cells. Other species behaved differently in different cells. For five of the six cells, calcium was consistently attenuated, and Ni, Na, SO_4, and Zn were consistently mobilized from the disposal medium layer.

For the five Alliance AFBC field cells, the behavior of leachates from the lower sample point was generally consistent throughout the period of field cell performance. The field cell containing coal mine interburden behaved quite differently from the other cells; the concentrations of most species were much higher for the lower than for the upper sample point, indicating that the field cell showed behavior similar to an acid mine drainage system. Other AFBC field cells showed a greater initial time of elution dependency than the PFBC field cells, probably because of low pH of leachates entering the disposal medium layer from the upper sample point.

A comparison of results for the post 60-day period was also made for the AFBC field cells. The replicate AFBC field cells (both containing alluvium) showed good agreement of A_F values for all species except calcium and iron. For each of these, one cell showed attenuation and the other showed mobilization. Comparison among the five cells for each species showed much less consistent results. Only aluminum, magnesium, and silicon behaved the same in all cells; aluminum and magnesium were consistently mobilized, and silicon was consistently attenuated. Nickel, zinc, and titanium were mobilized in all cells but one of the alluvium replicate cells.

In order to assess the permeability of FBC wastes and the change in permeability with time, two large (four-foot diameter) permeameters were filled with FBC waste; one contained Alliance AFBC waste and the other contained Georgetown AFBC waste. The permeability in each cylinder was measured initially after installation, again at an interim time, and finally at the conclusion of the field program. The double ring infiltrometer method was used. The Alliance AFBC permeameter was in place for 17 months, and the Georgetown AFBC permeameter was in place for about 12 months. During the period of operation, the Alliance AFBC waste permeability decreased from 1.1 $\times 10^{-3}$ cm/sec to 1.1 $\times 10^{-4}$ cm/sec. The Georgetown waste permeability decreased from 1.7 $\times 10^{-3}$ cm/sec to 1.7 $\times 10^{-5}$ cm/sec.

At the conclusion of the field studies, three of the Exxon PFBC and three of the Alliance AFBC field cells were cored to determine the physical condition of the wastes. The upper surfaces of all the waste masses were found to be "domed up" because of expansion, presumably due to additional hydration beyond the initial hydration undertaken when the cells were installed. The Exxon PFBC waste was found to be indurated and could be sampled only by drop hammer blows using a split-spoon sampler. The Alliance AFBC waste was much softer and more friable and could be sampled by a thin-walled sampler (Shelby Tube). A six- to nine-inch void was discovered between the waste layer and lower disposal medium layer in all PFBC cells; presumably this void was caused by "bridging" of the waste and settling of the lower disposal medium layer.

Prior to coring, an attempt was made to investigate the leachate residence time in the field cells by using radioactive tracer solutions in two Exxon PFBC and two Alliance AFBC cells. One conservative tracer (Br-82) and three nonconservative tracers (Ca-95, Sr-85, and Co-60) were used for this investigation. Unfortunately, none of the tracer solutions was detected at the upper sample point at any of the four field cells tested. Cores taken of the waste were returned to the lab and scanned for non-conservative tracers, but no evidence of the tracers was found in the waste. Subsequently, cores were taken of the upper disposal media layer at three of the field cells tested. A count-rate profile for Sr-85, Co-60, and Ca-45 showed that none of the tracer had passed through the upper foot of disposal media during the timeframe of the experiment.

E.2 Location and Description of the Crown Field Site

The site selected for the construction and operation of the field cells was the former EPA Mine Drainage Control field site at Crown (unincorporated), West Virginia, approximately nine miles southwest of Morgantown in

Monongalia County. The site is in a small valley which is roughly 1,000 feet in elevation. The surrounding hills are 1,200 to 1,300 feet in elevation. The field cells were constructed in an open, gently sloping field. The nearest obstructions are two one-story buildings approximately 100 feet away.

The climate of the Crown site is a "humid continental" type, with severe winters, moderately hot summers, and precipitation evenly distributed throughout the year. A climatological summary for a nearby National Weather Service Cooperative station at Mannington, West Virginia (16 miles west-southwest of the site) is presented in Table E-1. In addition to these data for Mannington, pan evaporation data are available for the Clarksburg, West Virginia weather station (25 miles southwest of the site) and are presented in Table E-2. Rainfall data were also collected at the Crown site during the program and are presented in a later section.

E.3 Field Cell Design and Construction

Several combinations of FBC wastes and disposal media were included in the field program. Project resources did not permit a full matrix of waste and disposal media combinations to be studied, so a reasonable subset of the full matrix was used (Table E-3). This matrix includes two control cells (containing disposal media only), two duplicate cells of Exxon PFBC waste and shale media, and two duplicate cells of Alliance AFBC waste and alluvium. These control and duplicate cells were included to aid in interpreting the results and for quality assurance and control purposes. The sources of the waste and disposal media in the field cells are described in Appendix A.

A prototype field cell was designed and constructed at Radian's headquarters in Austin, Texas in order to ensure smooth construction and operation procedures at the field site at Crown.

TABLE E-1. CLIMATOLOGICAL SUMMARY FOR MANNINGTON, WEST VIRGINIA

LATITUDE N39 33
LONGITUDE W80 21

CLIMATOLOGICAL SUMMARY

MEANS AND EXTREMES FOR PERIOD 1951-1973

MANNINGTON 1 N, WV
ELEVATION 975

MONTH	TEMPERATURE (°F)														PRECIPITATION TOTALS (INCHES)															
	MEANS			EXTREMES						MEAN NUMBER OF DAYS											SNOW, SLEET						MEAN NUMBER OF DAYS		
										MAX.		MIN.																	
	DAILY MAXIMUM	DAILY MINIMUM	MONTHLY	RECORD HIGHEST	YEAR	DAY	RECORD LOWEST	YEAR	DAY	90° AND ABOVE	32° AND BELOW	32° AND BELOW	0° AND BELOW	MEAN	GREATEST MONTHLY	YEAR	GREATEST DAILY	YEAR	DAY	MEAN	MAXIMUM MONTHLY	YEAR	GREATEST DEPTH	YEAR	DAY	.10 or MORE	.50 or MORE	1.00 or MORE
JAN	40.7	18.3	29.5	78	59	21	-26	63	29	0	8	27	3	2.97	5.56	52	1.99	53	8	10.1	21.5	66	15.0	66	30	8	2	0
FEB	43.8	20.5	32.2	74	72	29	-18	68	21	0	5	24	2	2.89	5.10	56	1.70	51	1	7.9	23.5	64	15.0	66	5	8	1	0
MAR	53.8	27.7	40.8	85	73	15	-12	60	8	0	1	22	0	3.72	7.07	63	1.95	67	6	6.0	18.5	60	12.0	60	5	9	3	1
APR	66.8	37.0	51.9	91	70	30	11	64	1	0	0	11	0	3.70	6.12	73	1.55	64	20	1.0	6.3	73	4.0	73	12	9	2	0
MAY	76.2	45.4	60.8	93	62	16	20+	66	10	1	0	3	0	4.15	9.75	68	3.42	56	27	.0	1.0	63				9	3	1
JUN	83.4	54.3	68.9	97	52	29	30	72	11	5	0	0	0	4.04	9.62	56	4.10	56	23	.0						7	3	1
JULY	85.9	58.7	72.3	99	66	3	36	63	4	8	0	0	0	4.60	8.42	58	3.27	52	4	.0						8	4	1
AUG	84.6	57.3	71.0	100+	53	30	37	65	29	5	0	0	0	4.39	10.07	54	2.86	58	14	.0						7	3	1
SEPT	79.3	50.2	64.8	102	53	3	21	62	21	3	0	1	0	3.19	7.98	71	2.60	71	12	.0						6	2	1
OCT	69.5	38.3	53.4	92	51	3	13+	65	29	0	0	9	0	2.59	6.02	54	3.50	54	15	.3	3.7	57	3.0	57	28	6	1	0
NOV	54.3	29.9	42.1	84	61	3	-2	58	30	0	1	19	0	2.89	5.27	51	1.45	61	24	2.6	9.5	71	5.0	67	30	7	2	0
DEC	43.8	22.9	33.4	77	51	7	-22	62	13	0	5	24	1	3.35	6.33	72	1.47	72	9	8.3	25.5	62	15.0	62	11	8	2	0
YEAR	65.1	38.4	51.8	102	53	SEP 3	-26	63	JAN 29	22	20	140	6	42.48	10.07	AUG 54	4.10	JUN 56	23	36.2	25.5	DEC 62	15.0	DEC 62	11	92	28	6

+ ALSO ON EARLIER DATES

TABLE E-2. AVERAGE MONTHLY PAN EVAPORATION FOR CLARKSBURG, WEST VIRGINIA WEATHER STATION (U.S. WEATHER BUREAU 1930-1962)

Month*	Evaporation (inches)
April	3.48
May	4.58
June	5.21
July	5.56
August	4.49
September	3.14
October	1.90
SEASONAL TOTAL	28.36

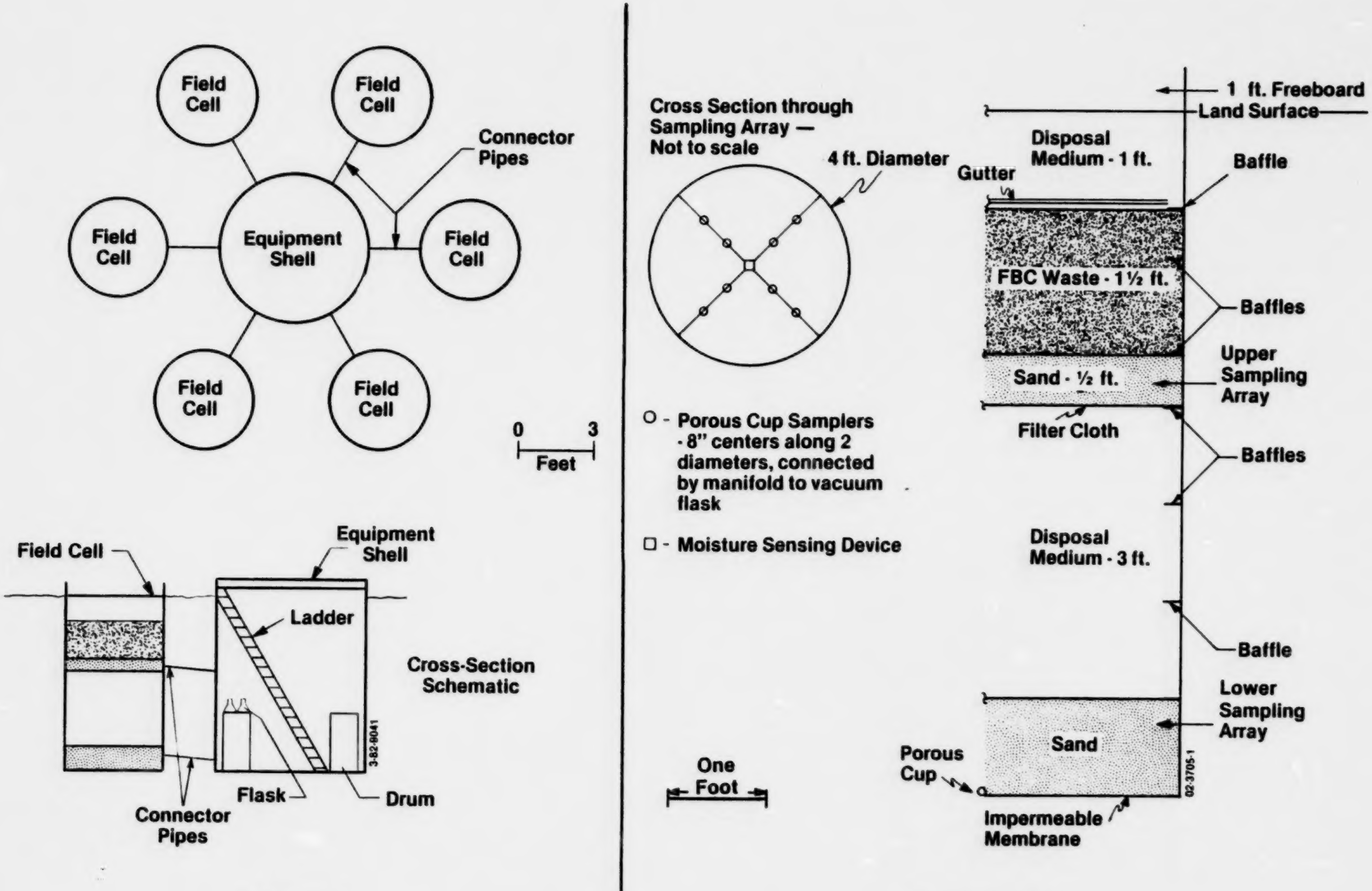
*Pan Evaporation from November through March is inconsequential.

TABLE E-3. TEST MATRIX FOR FIELD CELLS AT CROWN, WEST VIRGINIA

Disposal Medium	Control Cell (Media Only)	Exxon PFBC	Alliance AFBC	Total Cells
Shale	1	2	1	4
Interburden	—	—	1	1
Sandstone	—	1	—	1
Glacial Till	—	1	—	1
Alluvium	1	1	2	4
Limestone	—	1	1	2
TOTALS	2	6	6	13

E.3.1 Field Cell Design

The field cells were laid out in groups of six surrounding a central cylinder containing equipment (Figure E-1a). The overall geometry of each cell was a vertical cylinder containing a layer of waste emplaced over a layer of disposal medium (Figure E-1b). Above the waste was another layer of disposal medium. With the exception of the sand layer below the waste, a modification which was required for sampling, these field cells provided a reasonable simulation of an FBC landfill site.


Field Cell
Field Cell
Connector Pipes
Field Cell
Equipment Shell
Field Cell
Field Cell
Field Cell
0
3
Feet
Field Cell
Equipment Shell
Ladder
Cross-Section Schematic
3-82-8041
Flask
Drum
Connector Pipes
Cross Section through Sampling Array — Not to scale
4 ft. Diameter
○ - Porous Cup Samplers - 8" centers along 2 diameters, connected by manifold to vacuum flask
□ - Moisture Sensing Device
One Foot
1 ft. Freeboard
Land Surface
Disposal Medium - 1 ft.
Gutter
Baffle
FBC Waste - 1½ ft.
Baffles
Sand - ½ ft.
Upper Sampling Array
Filter Cloth
Baffles
Disposal Medium - 3 ft.
Baffle
Lower Sampling Array
Sand
Porous Cup
Impermeable Membrane
02-3705-1

a. Layout

b. Geometry

Figure E-1. Field Cell Layout and Geometry.

The cells were of sufficient scale that field simulation conditions were satisfied with reasonable construction and waste requirements. Also, they were made as large as practicable in order to minimize edge effects and to reduce the impact of inadvertent segregation of material during placement. The container was an eight-foot section of reinforced concrete pipe, 48 inches in diameter, which is the largest readily available size. The 48-inch diameter provided a significant increase over common laboratory scale. A large laboratory column might be as much as eight inches in diameter; the field cells had a cross-sectional area 36 times as large.

Installed in each field cell was a leachate sampling system. Immediately below the waste body was an array of porous cup samplers (upper sampling array of Figure E-1b) to sample leachate before it entered the underlying medium. Below the lower layer of disposal medium was a second set of porous cups (lower sampling array of Figure E-1b) to sample leachate after it had interacted with the medium. In the center of each array was a ceramic block soil moisture sensor; it was used to detect the presence or absence of significant quantities of water. The soil moisture sensor was used at the time of cell start-up to signal when leachate sampling might begin. Should any of the leachate sampling arrays have failed during operation, the sensor would have been used to check whether the difficulty was a lack of available water or mechanical failure of the sampling array. None of the sampling arrays failed during the field sampling program.

The porous cup sample array was devised to give an integrated sample on the entire cross section of the cell. It also produced water at a tolerable rate to minimize sampling time. Eight porous ceramic cups were fitted with nylon fittings cemented with epoxy adhesive. They were then connected with a manifold "harness" of flexible PVC tubing and nylon "T" connectors to a vacuum flask in the equipment shell, as shown in Figure E-2.

There existed a possibility that a perched water table would form at the upper surface of the waste body. A perforated pipe gutter was emplaced at the upper surface of the waste body to sample this perched water. During each sampling event, water that had collected in this gutter was pumped out.

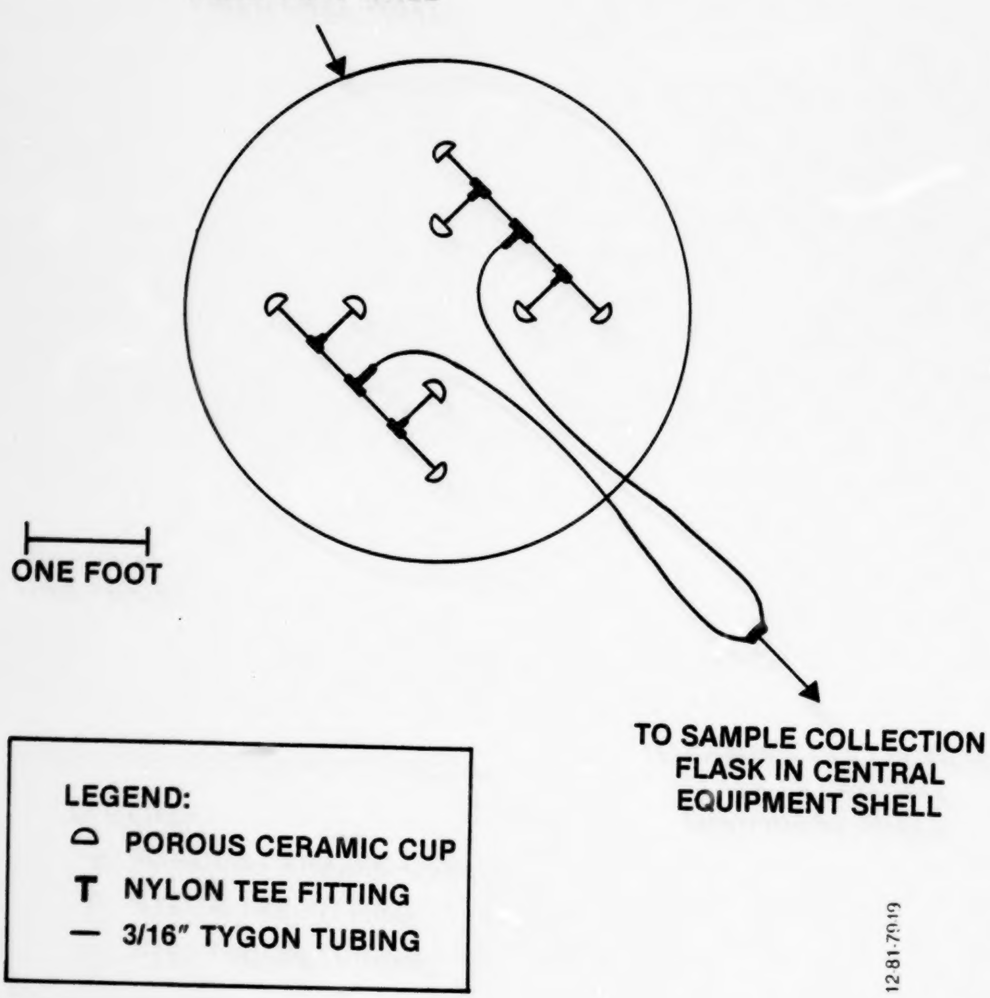

FIELD CELL WALL
ONE FOOT
TO SAMPLE COLLECTION FLASK IN CENTRAL EQUIPMENT SHELL
LEGEND:
⌓ POROUS CERAMIC CUP
T NYLON TEE FITTING
— 3/16″ TYGON TUBING
12 81-7919

Figure E-2. Detail of Porous Cup Sampling Array.

The sand layer below the waste layer served both as a "buffer zone" between the waste body and the underlying disposal medium layer and as a convenient site within which to bed the upper porous cup sample array and the soil moisture sensor. The leachate sampling array was used to draw off leachate samples prior to any contact with the underlying disposal medium.

Below the sand layer, the leachate passed through the lower layer of disposal medium where various physical and chemical processes occurred. The net effect of these processes was determined by sampling at the base of the disposal medium layer.

Below the lower disposal medium layer was a dual purpose sand layer. This layer contained the lower sampling array from which samples were extracted after exposure to the lower disposal medium. In addition, a single large porous ceramic cup or "filter candle" was installed at the base of the cell as a drain and was maintained at a constant 0.3 atmosphere tension. This filter candle prevented saturation of the field cell and also provided a means of removing all water throughput of the cell.

Diversion of leaching fluid from the contents of the column because of short-circuiting along the walls is a common problem for laboratory and field cells. Circumferential baffles were cemented to the walls of the field cells to prevent infiltrating rainfall or percolating leachate from channeling along the walls. The baffles were assembled from four-inch wide strips of 30 mil chlorinated polyethylene pond liner folded in half, lengthwise. One-half of the strip was cemented to the wall of the cylinder; the other half was laid out to form a horizontal baffle. Six baffles were emplaced in each cell, at the positions shown in Figure E-1b. Observations of field cell behavior indicated that significant short-circuiting did not occur. A limitation to the technique is that the cylinder must be large enough to allow access for installation. Installing the baffles and coating the interior of the cells is also a labor-intensive procedure requiring nearly a man-day per cell for installing baffles and handpainting the exposed concrete with coal tar epoxy. If the baffles had not been installed, the supplier could have coated the pipe much more efficiently as part of the manufacturing process.

As noted, the field cells were erected in a ring of six around a seventh, six-foot diameter central cylinder, which served as an equipment shelter and provided access for sampling as shown in Figure E-1a. The equipment shell was furnished with six drums connected by a manifold to a vacuum pump. Each drum serviced the large filter candle in the base of each field cell. There were also racks of vacuum flasks (two in series for each sample) to collect leachate samples.

E.3.2 Field Cell Construction

The field cells were completed and placed in operation as appropriate wastes became available. Cells 1 to 6, containing Exxon PFBC waste, were completed in July 1979 and placed in operation in August 1979. Control (media-only) cells were also initiated at this time. Cells 13 to 17, containing Alliance AFBC waste, were completed and placed in operation in March 1980. The contents of the various field cells are shown in Table E-4. The cells with no wastes shown were constructed in anticipation of availability of AFBC-with-carbon-burnup-cell waste for the test matrix. However, as noted in Appendix A, AFBC-with-CBC waste was not used in the program.

The three rings of six field cells, each with its central equipment shell, were set on end in a trench. Connector pipes were installed, and local soil was backfilled around the cells to within one foot of the top. The bottom of each cell was sealed with an impermeable liner, and succeeding layers of disposal media, sand and waste were emplaced by hand. Porous ceramic cup samplers and soil moisture sensors were emplaced in the sand layers.

TABLE E-4. CONTENTS OF FIELD CELLS AT CROWN, WEST VIRGINIA

Cell Number	Waste	Disposal Medium	Mass of Waste (10^6g)	Mass of Medium (10^6g)
1	Exxon PFBC	Shale	0.8	1.7
2	Exxon PFBC	Shale	0.8	1.7
3	Exxon PFBC	Till	0.8	1.2
4	Exxon PFBC	Limestone	0.8	1.8
5	Exxon PFBC	Alluvium	0.8	1.8
6	Exxon PFBC	Sandstone	0.8	1.8
7	None (control)	Shale	N/A[1]	3.3
8	NF[2]	Sandstone	–	1.8
9	NF	Alluvium	–	1.8
10	NF	Interburden	–	1.4
11	NF	Till	–	1.2
12	None (control)	Alluvium	N/A	3.0
13	Alliance AFBC	Interburden	0.8	1.4
14	Alliance AFBC	Alluvium	0.8	1.8
15	Alliance AFBC	Alluvium	0.8	1.8
16	Alliance AFBC	Limestone	0.8	1.8
17	Alliance AFBC	Shale	0.8	1.8
18	None (spare cell)	None	N/A	N/A

NOTE: Average mass per cell was 2.6 x 10^6g

[1] N/A = Not applicable.

[2] NF = Not filled.

The cells were filled by hand-placing the material in layers as shown in Figure E-1b. Disposal media were brought from on-site stockpiles in bulk and were shoveled into each cell from the land surface. Media were emplaced in level lifts but not compacted. In the case of the coarse-textured media (shale and sandstone), particles larger than approximately four inches were discarded.

FBC wastes, received as separate waste run streams, were mixed in a rotating drum cement mixer in the same ratio as the original production rates. The bulk densities of the individual waste streams were determined on-site, and the actual mixing was done by volume. Deionized water was added to satisfy the initial hydration requirements of the waste. After the cells were completed, they were irrigated with deionized water to bring them to field capacity.

E.4 Field Cell Operation and Sampling

In principal, the field cells were merely left exposed to natural rainfall. One of the objectives of the experiment was to observe the consequences of such exposure. The field cells were initially irrigated with deionized water to field capacity and thereafter exposed only to natural precipitation.

Infiltrating precipitation passed through the upper layer of disposal medium and became geochemically equilibrated with it. The water then passed through the waste body, leaching soluble constituents from the wastes. Inasmuch as the infiltrate then migrated from a fine-grained into a coarse-grained porous medium, the lower portion of the waste body probably became saturated (because of capillarity) and remained saturated during the full course of the experiment.

During sampling, a 550 mL sample was collected at each sample point for chemical analysis. Each sample was split and preserved as shown in Figure E-3 and shipped to Radian laboratory facilities in Austin for the analyses shown in the figure.

During each sampling event, water that had collected in the impermeable gutter at the upper surface on the waste body was pumped out. Only a few samples were obtained during the study.

Mass flow of water through the cells was measured and recorded as input and output. Precipitation input to the cells was monitored by a recording rain gage installed on-site. Supplemental irrigation that was applied to bring the cells up to field capacity was metered. The throughput removed by the filter candle in the base of each cell accumulated in a 30-gallon drum (one per cell) in the central equipment shelter of each field cell array. These drums were pumped out periodically, and the accumulated volume was measured. The volume in the drum, plus quantities removed from the gutter and by the sample arrays, was recorded as cell throughput.

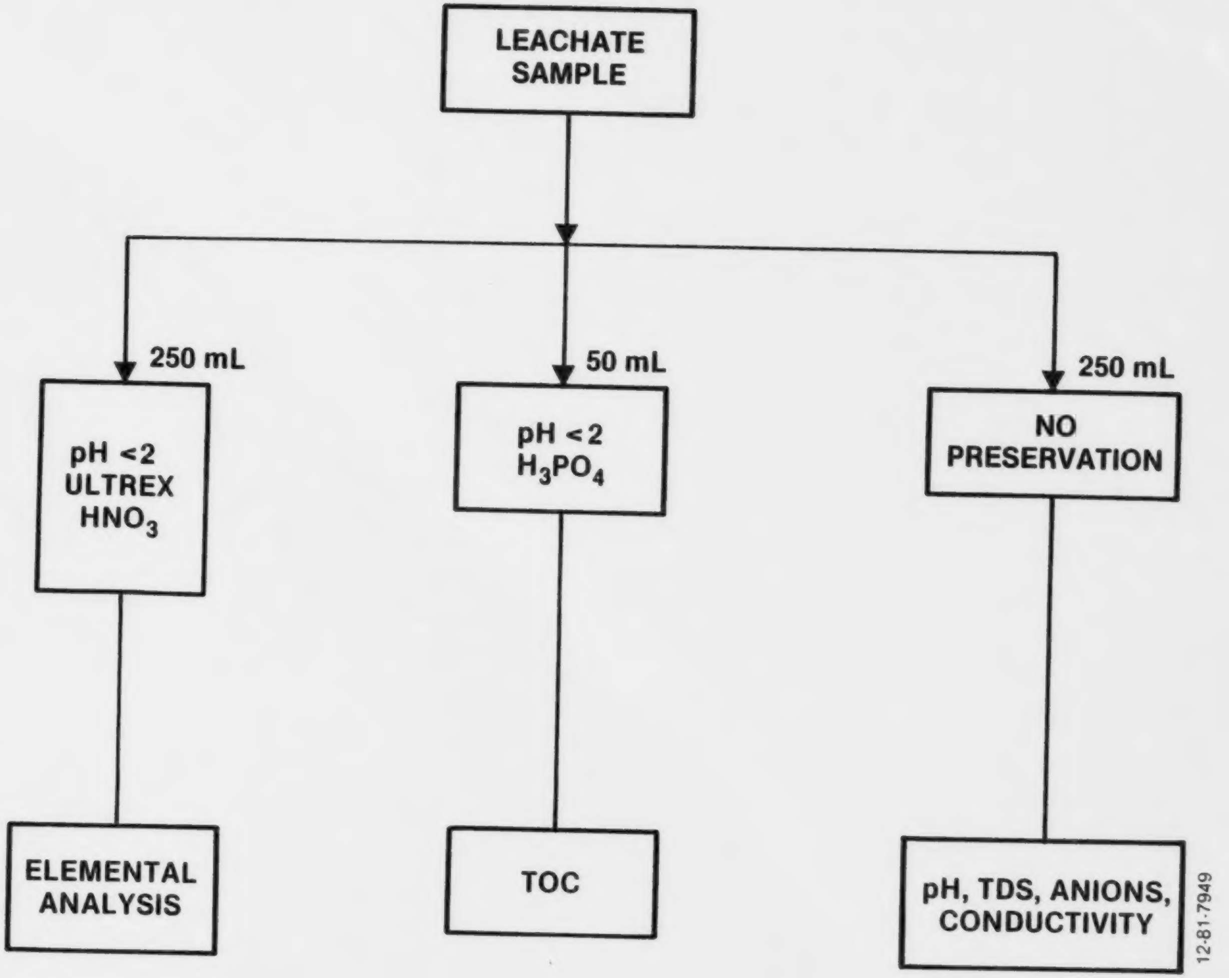

LEACHATE SAMPLE
250 mL
50 mL
250 mL
pH <2 ULTREX HNO3
pH <2 H3PO4
NO PRESERVATION
ELEMENTAL ANALYSIS
TOC
pH, TDS, ANIONS, CONDUCTIVITY
12-81-7949

Figure E-3. Procedures for Splitting, Preservation, and Analysis of Field Cell Leachate Samples.

Sample collection frequency had an increasing period, beginning with the first appearance of leachate. Projected sample days were roughly equally spaced along a logarithmic time scale. A total of 25 sample events were scheduled for Cells 1-6 (containing PFBC waste) and control Cells 7 and 12 as shown in Table E-5. Also shown in the table are "actual" sample days and dates of collection. By the time Cells 13-17 (containing AFBC waste) were emplaced, observations on the first set revealed that the same information was obtained with a sparser data set. Therefore, only 20 sample events were scheduled for Cells 13-17. Scheduled and "actual" sample days for Cells 13-17 are shown in Table E-6. The last scheduled sample event was superceded by the 6-month, intensive sampling effort for all field cells shown on Table E-7. Samples were collected on or about the 15th of each month from July through November 1981.

The departure of actual sample days from the scheduled or expected day was a result of the variability of the rainfall input. After the operating cells were brought to field capacity, no additional irrigation was applied. In the absence of significant rainfall, very little sample could be extracted. The variability in the sample schedule is a direct result of the variability in the appearance of leachate.

For the first portion of the sampling period, the leachate collection systems were maintained under a constant vacuum. Thus, the leachate collected represented a time-composite of all flows since the preceding collection. Samples 1-12 were collected in this manner. As the interval between sampling events increased, it became less desirable to attempt to continue the sampling. Vacuum flasks were filled to capacity within a few days and began to overflow. Subsequent leachate withdrawals were incompletely mixed with flask contents or flowed to waste in one of the drums. Installing the larger vacuum flasks merely postponed onset of this difficulty.

The upper sampling array, if operated continuously, removed a significant fraction of the leachates. More importantly, since flow through the field cells varied with time (both in quantity and quality), a time-composite of such a flow system was unrealistic, and hence, undesirable.

TABLE E-5. SAMPLE SCHEDULE FOR FIELD CELLS 1 THROUGH 6 (EXXON PFBC WASTES) AND CELLS 7 AND 12 (CONTROLS)

Sample Number	Scheduled Day	Actual Day	Actual Date
1	1	1	4 August 1979
2	2	3	6 August 1979
3	3	4	7 August 1979
4	4	5	8 August 1979
5	5	8	11 August 1979
6	6	9	12 August 1979
7	8	11	14 August 1979
8	10	13	16 August 1979
9	13	16	19 August 1979
10	16	21	24 August 1979
11	20	25	28 August 1979
12	25	30	2 September 1979
13	32	37	9 September 1979
14	49	48	20 September 1979
15	50	57	29 September 1979
16	63	72	14 October 1979
17	79	90	1 November 1979
18	100	113	24 November 1979
19	126	133	14 December 1979
20	158	167	17 January 1980
21	200	216	6 March 1980
22	251	269	28 April 1980
23	316	331	29 June 1980
24	398	405	11 September 1980
25	501	511	26 December 1980

TABLE E-6. SAMPLE SCHEDULE FOR FIELD CELLS 13 THROUGH 17 (ALLIANCE AFBC WASTES)

Sample Number	Scheduled Day	Actual Day	Actual Date
1	1	1	21 March 1980
2	2	2	22 March 1980
3	3	3	23 March 1980
4	4	4	24 March 1980
5	6	6	26 March 2980
6	8	8	28 March 1980
7	11	11	31 March 1980
8	15	15	4 April 1980
9	21	21	10 April 1980
10	30	30	19 April 1980
11	42	53	12 May 1980
12	58	61	10 May 1980
13	82	84	12 June 1980
14	114	125	23 July 1980
15	160	167	3 September 1980
16	205	214	20 October 1980
17	251	253	28 November 1980
18	316	316	30 January 1981
19	398	400	24 April 1981
20	501	– superceded	–

TABLE E-7. INTENSIVE SAMPLING SCHEDULE FOR ALL FIELD CELLS

Sample Number for Cells 1-7, 12	Sample Number for cells 13-17	Date
26	20	18 June 1981
27	21	17 July 1981
28	22	17 August 1981
29	23	17 September 1981
30	24	19 October 1981
31[1]	25[2]	6 November 1981

[1] Cells 2, 3 and 5 not sample, due to dismantling and coring.

[2] Cells 13, 14, and 17 not sampled, due to dismantling and coring.

Accordingly, the sample collection scheme was modified for sample 13 and subsequent samples. On an assigned "sample day" the operator turned on the sampling system and awaited a precipitation event. He returned the day following such a precipitation event, collected a sample, and turned off the system. This procedure provided a sample representative of conditions at the time, rather than an imperfect composite of previous conditions.

The specific sampling procedures in the field consisted of the following steps:

- Each drum was pumped out, and the quantity of throughput and pH and electrical conductivity of the contents of each drum were measured and recorded;

- The racks containing the vacuum flasks were removed for breakdown; the volume in each vacuum flask was recorded, and the contents of the two flasks servicing a single sample point were composited;

- The pH and electrical conductivity of each sample were measured, and the sample was split and preserved as shown in Figure E-3, according to a written protocol;

- Vacuum was reapplied to the drums, the vacuum flask racks were reassembled, but not connected to vacuum, and the site secured;

- Samples were packed in ice chests and shipped to Radian's laboratories in Austin for analysis; and

- At monthly intervals, the chart and batteries for the recording rain gage were changed.

E.5 Hydrologic Balance of the Field Cells

In order to estimate losses from evaporation or other sources, the mass balance of water through the field cells was evaluated. As noted, the field cells were completed and placed in operation in two groups. The cells containing Exxon PFBC wastes (Cells 1-6) and the two control cells (Cells 7 and 12) were started in August, 1979. For convenience, they are termed "the PFBC and control cells". The cells containing Alliance AFBC wastes (Cells 13-17) were started in March, 1980. They are termed "the AFBC cells".

E.5.1 Instrumentation and Data Collection

Precipitation on the site was measured with a ground-mounted, standard weighing rain gage. Data from this rain gage, in the form of daily precipitation totals, were transcribed into the SAS data base and converted to volume of water per cell. These precipitation data, along with records of initial and supplemental irrigation, provided the measure of gross water input to the field cells. The record of precipitation and irrigation for each set of cells is shown in Appendix J.

The water which flowed through the field cells was also measured and recorded. As noted, the base of each cell was sealed with an impermeable membrane to prevent leachate escape. A large porous ceramic cup (filter candle), which was emplaced immediately above this membrane, was connected by a tube with a 30-gallon drum in the central equipment shelter. The filter candle was maintained under a constant 0.3 atmosphere (10 inches of mercury) tension to remove water reaching the base of the cell and to maintain unsaturated conditions in the cell. Periodically, the 30-gallon drums were pumped out, and the quantity of water which had accumulated was recorded. When a sample was collected from the upper and lower sample points, the quantity of leachate in the collection flasks was also noted. The sum of the water removed by the sample collection array and the filter candle was transcribed into the SAS data base as cell throughput. This was the net output of the field cell.

E.5.2 Sources of Water Losses from the Field Cells

The losses from the system were measured as the difference between gross input and net output. The most significant loss was by evaporation from the cell surface and from water standing on the surface of the cell. Any time that the rate of precipitation exceeded the rate of infiltration, water accumulated on the cell surface and was exposed to evaporative losses. Additionally, during extended periods of heavy rainfall, the available freeboard (6 inches minimum) was exceeded and some of the cells overflowed.

Other sources of losses from the system were considered, evaluated and discounted. The field cells themselves appear to have been as efficient as rain-fall receptors as was the rain gage. Four small (~2" diameter) receptacles were placed at random locations within each of four field cells, and the accumulated depth was measured after three rainfall events. In each case, the measurements showed a uniform distribution of precipitation over the cell surface and a precipitation depth was equal to the rain gage catch.

The constant-vacuum filter candles appear to have been effective in quantitatively removing leachate at the bottom of the cells. All the drains continued to operate during the life of the project (i.e., there was no loss of integrity). Additionally, when six of the cells were cored at the close of the project, no free water was found in the lower sand layer of any cell.

In consideration of the above, all the water losses from the system are ascribed to evaporation from the cell surface and cell overflow.

E.5.3 Hydrologic Performance of the Exxon PFBC and Control Cells

The Exxon PFBC and control cells were operated from 1 August 1979 to 26 December 1980 (Table E-5). They were then covered so that no additional precipitation could enter. They were placed in service again on 1 June 1981, as part of an intensive six-month sampling effort (Table E-7). The complete precipitation record for the Exxon PFBC and control cells is presented in Attachment 3. A plot of the cumulative rainfall volume is shown on Figure E-4.

The average water throughput of Cells 1 to 6 is shown in Figure E-5 and Table E-8. The column headed "Day (A)" displays the elapsed calendar days since the cells were placed in operation. The column headed "Day (O)" displays the elapsed days of cell operation, accounting for the 180-day hiatus. In the interest of internal consistency, the averages are shown only for cells which contain waste (Cells 1 to 6). A double-mass curve of rainfall versus average throughput is shown in Figure E-6. Both Figure E-4 and E-5 display cumulative volumes versus days of operation. The six-month hiatus in cell operation is marked on the figures. The throughput data for individual PFBC cells and control cells are shown in Tables E-9 through E-16 (see Attachment 1). This discussion of water balance, however, will focus on the 17-month (514-day) period from 1 August 1979 to 26 December 1980. This period of sufficient length to constitute a representative record and is uncomplicated by the six-month hiatus in the operation.

A summary of the water balance data is presented in Table E-17. The average throughput and losses were computed only for cells which contain waste (Cells 1 to 6). The PFBC cells each received a total input of 2,135 L, which is equivalent to 1829 mm of precipitation. The average losses for the cells containing waste were 950 L (814 mm), or 44% of gross input. When adjusted to an annual basis, the losses are equivalent to 578 mm per year, which is compatible with the measured pan evaporation rate at Clarksburg, WV, of 28.36 inches (720 mm) per year (Table E-3). The range of throughput among the cells is significant, as shown on Table E-17. In general, the cells containing coarser-grained materials had higher throughputs, reflecting their higher permeability and consequent lower evaporative losses. The greatest losses occurred from the alluvium control cell, which would have provided the greatest opportunity for evaporative losses from the deep layer of fine-grained materials. The total losses from this cell were 1,129 L (967 mm) which is equivalent to an annual rate of 687 mm. This rate is also compatible with the measured pan evaporation rate of 720 mm per year.

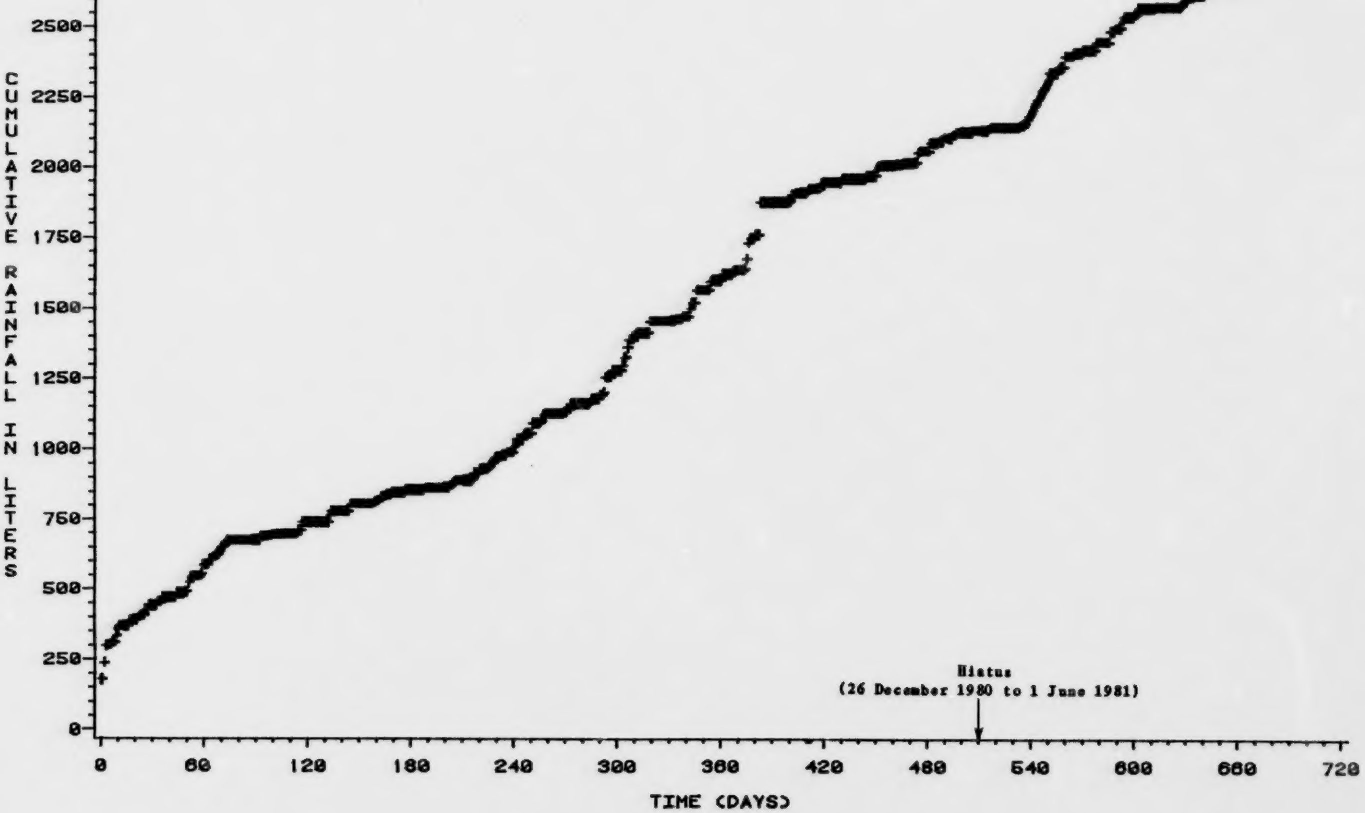


Figure E-4. Cumulative Rainfall for Exxon PFBC and Control Cells.

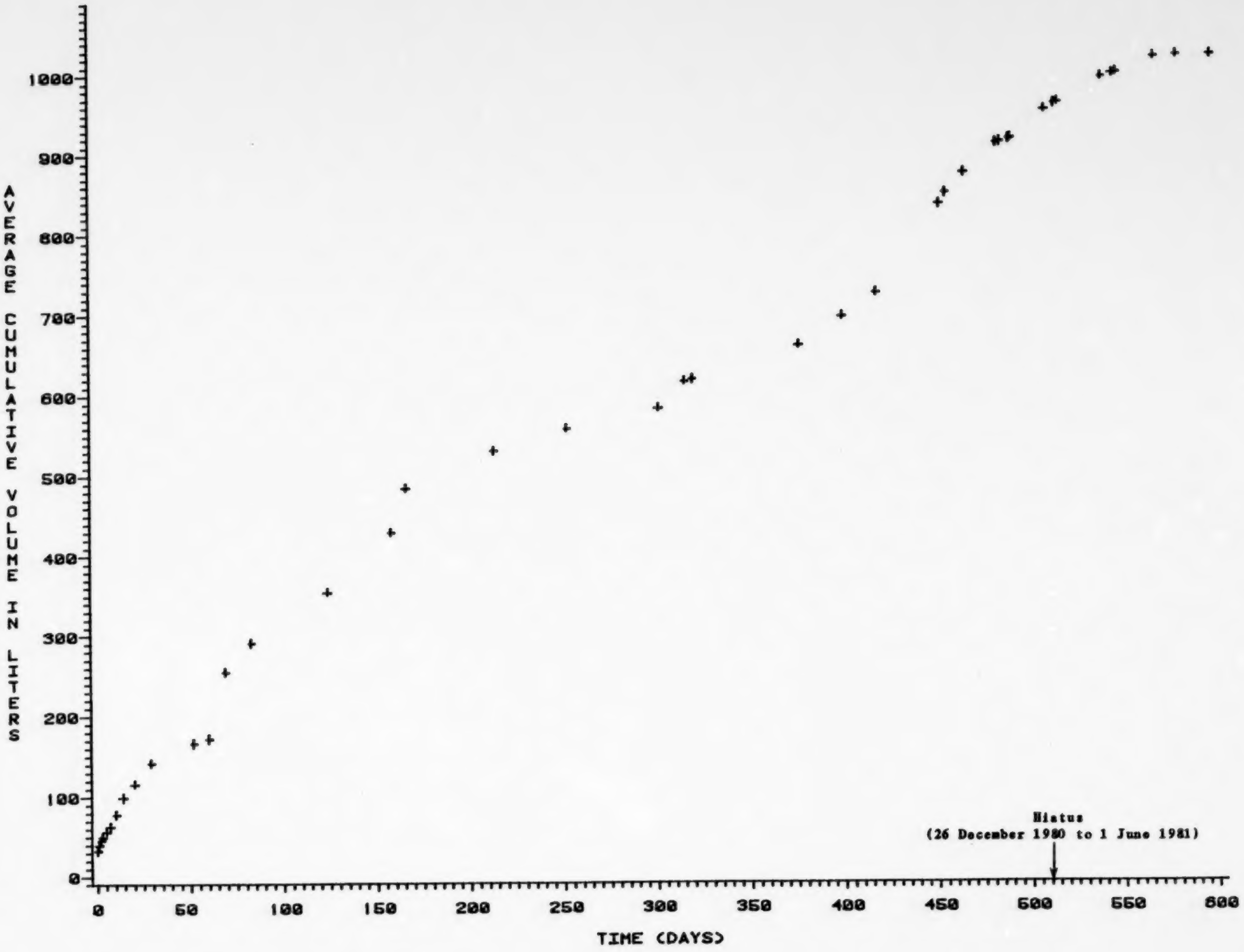


Figure E-5. Average Water Throughput for Exxon PFBC Field Cells (1 to 6).

TABLE E-8. AVERAGE AND CUMULATIVE THROUGHPUT VOLUMES FOR EXXON PFBC CELLS (1 TO 6)

DATE	DAY_A	DAY_O	AVE_VOL	CUM_VOL
04AUG79	0	0	6.366	6.37
06AUG79	2	2	14.145	20.51
07AUG79	3	3	8.459	28.97
08AUG79	4	4	2.044	31.01
11AUG79	7	7	7.516	38.53
12AUG79	8	8	11.357	49.89
14AUG79	10	10	16.211	66.10
16AUG79	12	12	14.301	80.40
19AUG79	15	15	12.562	92.96
24AUG79	20	20	13.512	106.47
28AUG79	24	24	13.351	119.82
02SEP79	29	29	16.173	136.00
09SEP79	36	36	15.224	151.22
20SEP79	47	47	13.045	164.27
29SEP79	56	56	31.502	195.77
14OCT79	71	71	61.268	257.04
01NOV79	89	89	39.507	296.55
04NOV79	92	92	5.355	301.90
24NOV79	112	112	28.064	329.96
14DEC79	132	132	39.091	369.06
17JAN80	166	166	68.270	437.33
06MAR80	215	215	64.410	501.74
31MAR80	240	240	63.667	565.40
28APR80	268	268	85.441	650.84
22MAY80	292	292	43.167	694.01
13JUN80	314	314	24.167	718.18
29JUN80	330	330	65.481	783.66
08AUG80	370	370	106.500	890.16
26AUG80	388	388	40.500	930.66
11SEP80	404	404	79.800	1010.46
20OCT80	443	443	37.500	1047.96
20DEC80	504	504	108.667	1156.62
26DEC80	510	510	28.033	1184.66
17JUN81	683	548	41.205	1225.86
28JUN81	694	559	62.100	1287.96
15JUL81	711	576	62.833	1350.80
17JUL81	713	578	1.840	1352.64
22JUL81	718	583	2.333	1354.97
23JUL81	719	584	0.750	1355.72
10AUG81	737	602	86.033	1441.75
15AUG81	742	607	20.167	1461.92
17AUG81	744	609	1.602	1463.52
09SEP81	767	632	49.000	1512.52
15SEP81	773	638	3.333	1515.85
17SEP81	775	640	1.818	1517.67
07OCT81	795	660	30.000	1547.67
19OCT81	807	672	1.886	1549.56
06NOV81	825	690	1.079	1550.64

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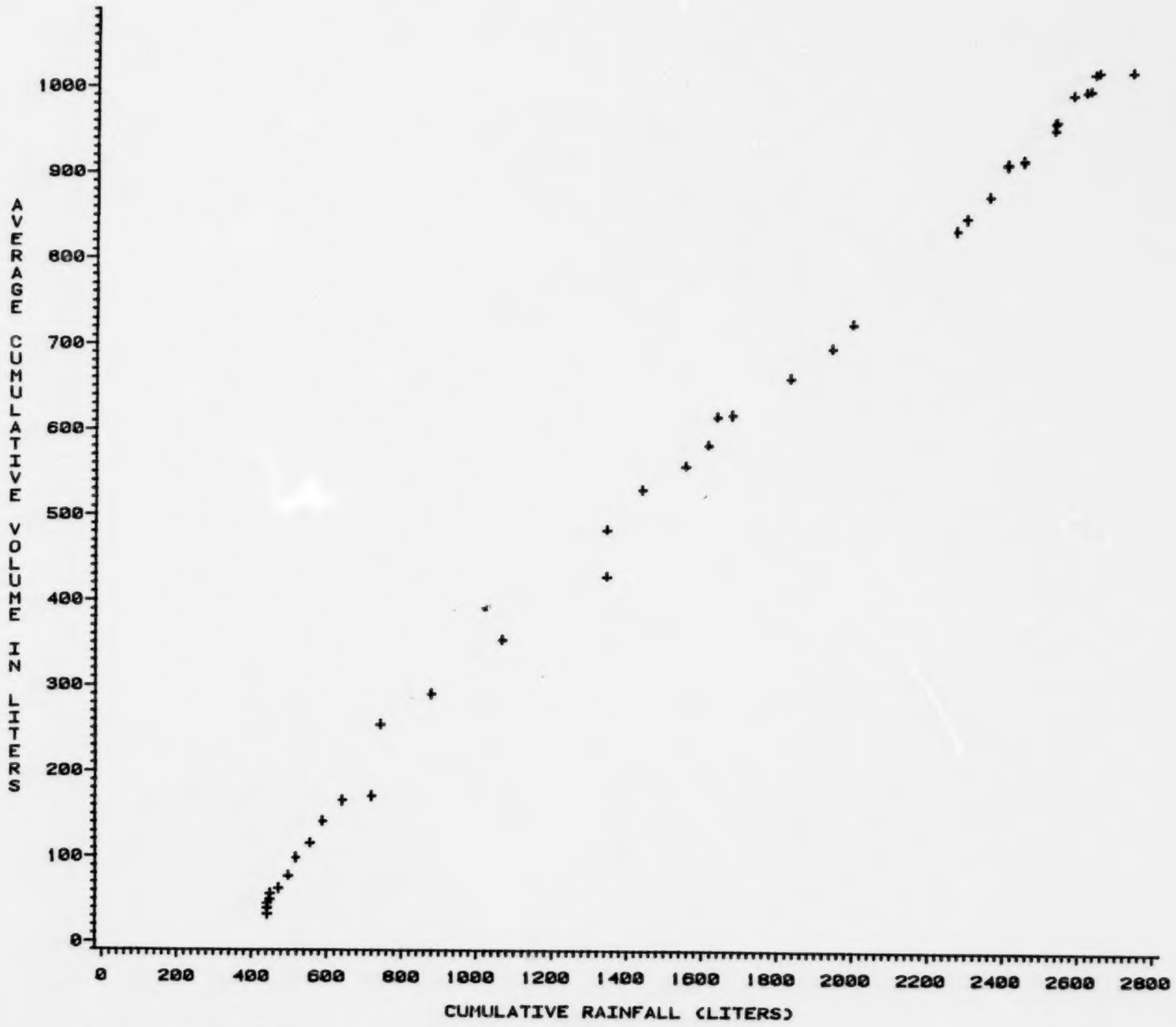


Figure E-6. Plot of Rainfall and Throughput Volumes for Exxon PFBC Field Cells (1 to 6).

TABLE E-17. WATER BALANCE OF EXXON PFBC AND CONTROL CELLS FOR THE PERIOD 1 AUGUST 1979 THROUGH 26 DECEMBER 1980

Cell Number	Contents	Throughput (L)	Losses (L)
1	PFBC/Shale	1,276	859
2	PFBC/Shale	1,299	836
3	PFBC/Till	1,079	1,056
4	PFBC/Limestone	1,207	928
5	PFBC/Alluvium	1,060	1,075
6	PFBC/Sandstone	1,186	949
7	Shale Control	1,281	854
12	Alluvium Control	1,006	1,129

Total Input = 2,135 L (1,829 mm)
Average Throughput = 1,185 L (1,015 mm) (Cells 1 to 6, only)
Average Losses = 950 L (814 mm) (Cells 1 to 6 only)

E.5.4 Hydrologic Performance of the Alliance AFBC Cells

The Alliance AFBC cells (Cells 13 through 17) were placed in service on 16 March 1980 and were operated continuously until the close of the experiment on 6 November 1981, a period of 601 days (Table E-6). The record of total precipitation input is presented in Attachment 4 and plotted on Figure E-7. The average throughput record for all of the cells is presented in Table E-18 and plotted on Figure E-8. A double-mass curve of rainfall volume versus average throughput is presented on Figure E-9. The records of individual cells are given in Table E-19 to E-23 (see Attachment 2). Three of the six cells were destroyed by the coring operation after the 19 October 1981 sampling event (see Section E.9), and no flow records were obtained thereafter. Therefore, the water balance calculations were applied to data collected through 19 October 1981. A summary of the water balance data is presented in Table E-24.

During the period of observation, the cells were exposed to a total of 2,645 L (2266 mm), which is equivalent to an annual rate of 1,419 mm, slightly more than that which the Exxon PFBC cells received. Of the total

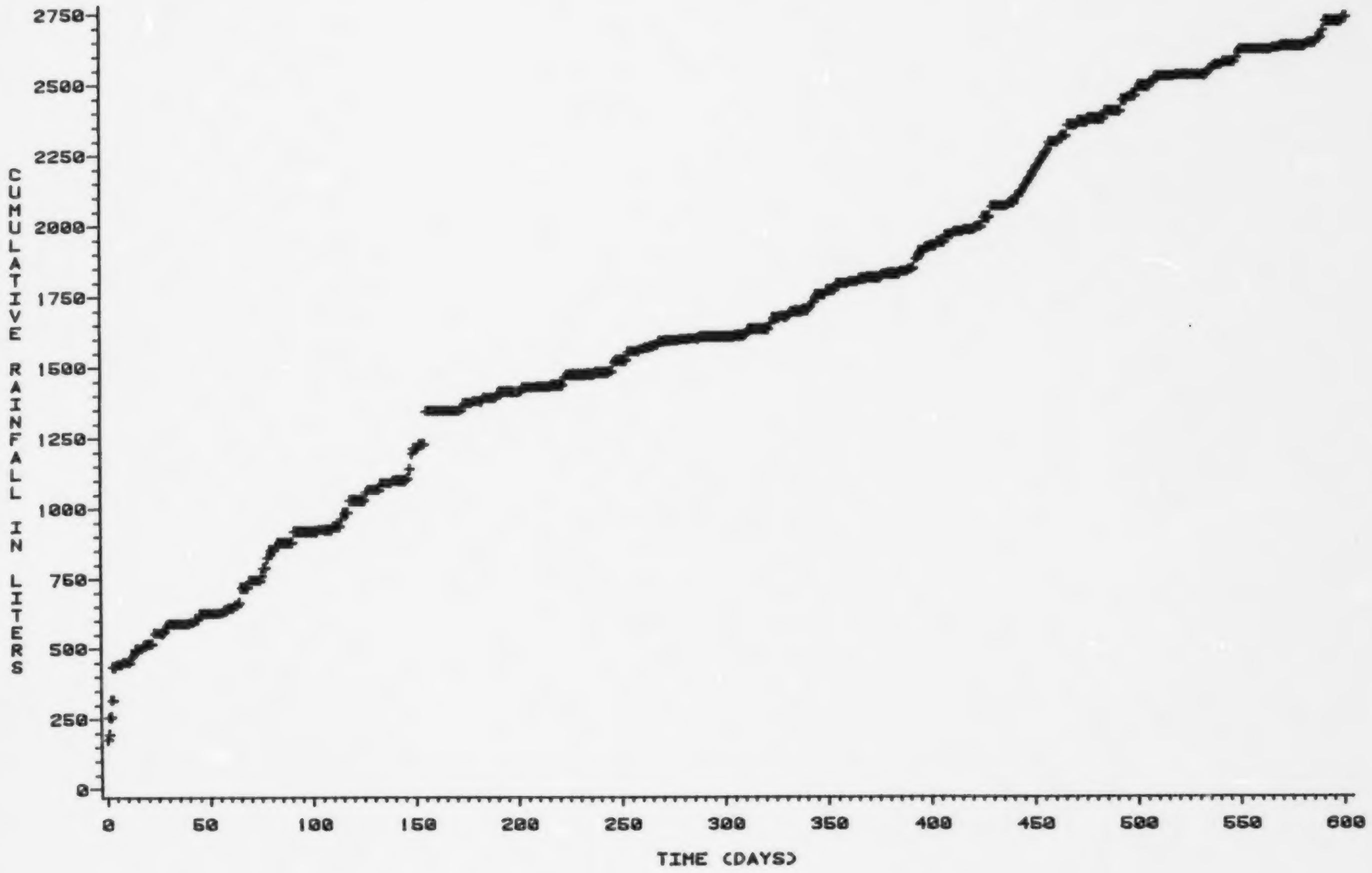


Figure E-7. Cumulative Rainfall for Alliance AFBC Field Cells.

TABLE E-18. AVERAGE AND CUMULATIVE THROUGHPUT VOLUMES FOR ALLIANCE AFBC FIELD CELLS (13 TO 17)

DATE	DAY_A	DAY_D	AVE_VOL	CUM_VOL
21MAR80	0	0	33.290	33.29
22MAR80	1	1	6.917	40.21
23MAR80	2	2	5.896	46.10
24MAR80	3	3	4.052	50.15
26MAR80	5	5	6.916	57.07
28MAR80	7	7	6.222	63.29
31MAR80	10	10	14.537	77.83
04APR80	14	14	21.289	99.12
10APR80	20	20	16.635	115.75
19APR80	29	29	25.752	141.51
12MAY80	52	52	25.034	166.54
20MAY80	60	60	5.301	171.84
29MAY80	69	69	83.000	254.84
12JUN80	83	83	36.676	291.52
23JUL80	124	124	62.823	354.34
26AUG80	158	158	74.800	429.14
03SEP80	166	166	55.123	484.26
20OCT80	213	213	46.500	530.76
28NOV80	252	252	28.174	558.94
16JAN81	301	301	24.800	583.74
30JAN81	315	315	33.200	616.94
03FEB81	319	319	2.673	619.61
01APR81	376	376	42.200	661.81
24APR81	399	399	35.965	697.77
12MAY81	417	417	28.200	725.97
15JUN81	451	451	111.200	837.17
18JUN81	454	454	13.845	851.02
28JUN81	464	464	25.400	876.42
15JUL81	481	481	37.000	913.42
17JUL81	483	483	1.555	914.97
22JUL81	488	488	3.600	918.57
27JUL81	489	489	0.600	919.17
10AUG81	507	507	35.800	954.97
15AUG81	512	512	8.000	962.97
17AUG81	514	514	1.441	964.42
09SEP81	537	537	31.200	995.62
15SEP81	543	543	4.000	999.62
17SEP81	545	545	1.443	1001.06
07OCT81	565	565	19.600	1020.66
19OCT81	577	577	1.593	1022.25
06NOV81	595	595	0.545	1022.80

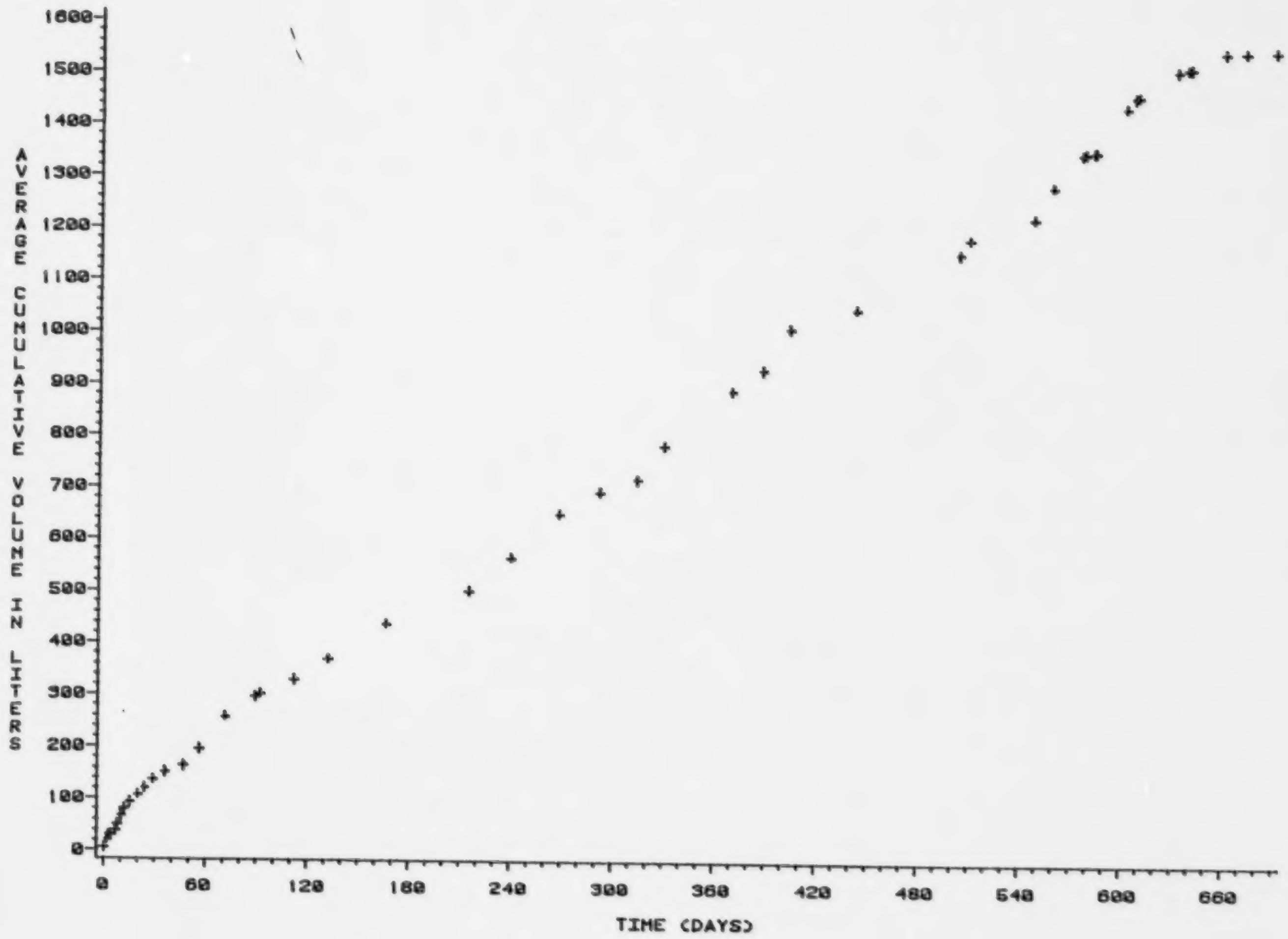


Figure E-8. Average Water Throughput for Alliance AFBC Field Cells (13 to 17).

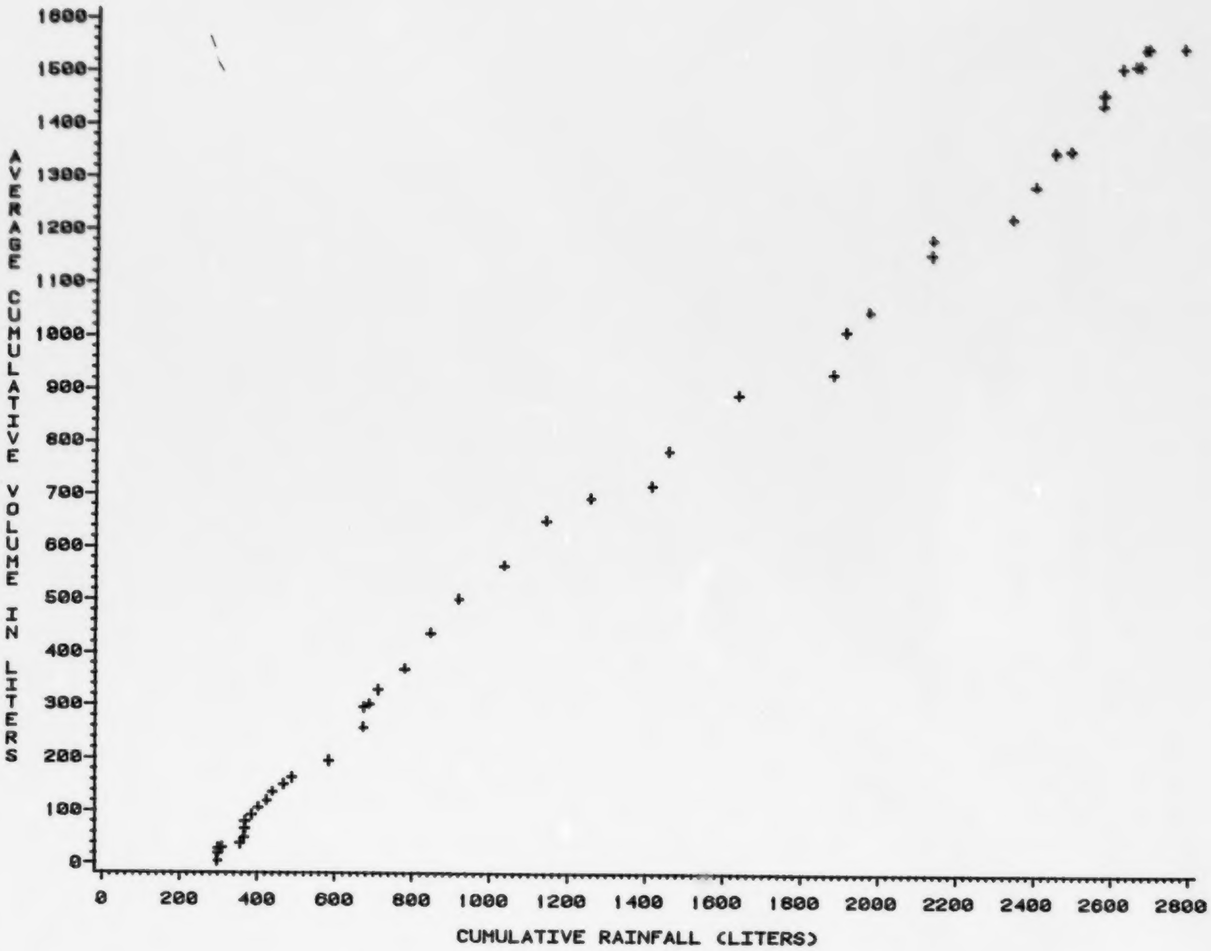


Figure E-9. Plot of Rainfall and Throughput Volumes for Alliance AFBC Field Cells (13 to 17).

2,645 L, an average of 1,022 L appeared as throughput, leaving 1,623 L as net losses, or 61% of gross input. The loss rate is equivalent to 870 mm per year, which is somewhat higher than that experienced by the Exxon PFBC cells (578 mm/yr) and also higher than the average annual pan evaporation (720 mm) at Clarksburg, WV (Table E-3). This large loss rate may be ascribed to two phenomena. First, the period of operation spans two summers, when evaporative losses are high, so that the 19 months of operation are equivalent to 24 months of evaporative losses which, on the average, would have approached 1,400 mm. Second, the set of Alliance AFBC cells were often noted to have standing water or to be overflowing, so that the losses from cell overflow would have been higher than those of the Exxon PFBC cells.

The range of throughput among the cells is again significant, as shown on Table E-24. The smallest throughput (largest losses) occurred in the cell containing AFBC waste and shale. The total losses from this cell were 1,907 L, which is equivalent to an annual rate of 1,022 mm.

TABLE E-24. WATER BALANCE OF THE ALLIANCE AFBC CELLS FOR THE PERIOD 16 MARCH 1980 THROUGH 19 OCTOBER 1981

Cell Number	Contents	Throughput (L)	Losses (L)
13	AFBC/Interburden	1,326	1,319
14	AFBC/Alluvium	1,193	1,452
15	AFBC/Alluvium	873	1,772
16	AFBC/Limestone	981	1,664
17	AFBC/Shale	738	1,907

Total Input = 2,645 L (2,266 mm)
Average Throughput = 1,022 L (875 mm)
Average Losses = 1,623 L (1,390 mm)

E.6 Permeability Determinations in Large Field Permeameters

In planning for waste disposal facilities, it is important to understand how chemical and mechanical weathering affect hydrologic properties of

FBC wastes over time. In an attempt to observe these properties, two large permeameters were assembled and exposed to weather conditions for the duration of the field studies. One permeameter was filled with Alliance AFBC waste and one with Georgetown AFBC waste. The wastes were hydrated prior to emplacement in the same way as the wastes that were put in the field cells. Infiltration measurements were taken three times during the field studies: once shortly after emplacement of the wastes; once at an interim period; and finally at the end of the field studies.

E.6.1 Permeameter Design and Operation

To study changes in permeability characteristics of FBC wastes with time, chemical changes, and exposure to weathering, two large permeameters were constructed from reinforced concrete pipe, four feet high and four feet in diameter. To maintain unsaturated conditions, these cylinders were set on end and placed on a pad of ungrouted concrete blocks. The bottom of each cylinder was lined with filter fabric. A 30-inch lift of waste, bounded above and below by a six-inch lift of silica sand was emplaced in each permeameter. A six-inch freeboard was left to prevent surface runoff. To accelerate weathering of the wastes, the permeameters were left above ground where they were exposed to maximum temperature fluctuations. The schedule for permeameter construction and testing is shown in Table E-25.

TABLE E-25. SCHEDULE OF PERMEABILITY TESTS

	Alliance AFBC Cell	Georgetown AFBC Cell
Installation	15 March 1980	7 October 1980
Initial Infiltration Test	1 May 1980	6 November 1980
Interim Infiltration Test	28 July 1981	29 July 1981
Final Infiltration Test	28 October 1981	27 October 1981

Infiltration tests were conducted using the double ring infiltrometer method (Reference E-1). This method was modified for use in the permeameters by allowing the permeameter container to serve as the outer ring.

Replicate measurements at two sites on the waste surface were taken within the same permeameter using two infiltrometers (steel cylinders that were 12 inches in diameter and 14 inches high). These cylinders were strong enough to drive but thin enough to enter the wastes with minimum disturbance. They were driven into the wastes vertically to a depth of approximately seven inches with the aid of a metal plate, a four-pound mallet and a carpenter's level. The overlying layer of silica sand was removed to allow water to enter the wastes directly, and a centimeter scale was placed on the inside of each cylinder for water level readings. Water was initially added to the infiltrometer rings to a depth of approximately seven inches. The water level was immediately recorded as the level at time T=0. Measurements of the fall of the water surface were recorded at the end of 1, 2, 3, 5, 10, 15, 20, 30, 60, 90, and 120 minutes, and hourly thereafter, up to six hours or when the infiltration rate stabilized. During measurements, the wastes outside the cylinders were kept moist to prevent significant lateral movement of water from under the cylinders. If the water level within a cylinder dropped about six inches, water was added to its initial depth. The water levels before and after refilling were recorded, and subsequent rates were appropriately calculated with the new levels.

During the early portions of each test, the waste accepted water rapidly as the wetting front of infiltrating water expanded into the relatively dry material. As the test continued, the rate of intake slowed and gradually approached a constant, which is termed the "final infiltration capacity". For purposes of this study, the final infiltration capacity is a measure of the permeability and would be expected to change as the physical properties of the material change over a period of time.

E.6.2 Permeability Results

For each of the three tests, results were calculated for cumulative water intake and average infiltration capacity versus time for the duration of the test. Cumulative water intake over time is the parameter measured in the field. Average and final infiltration rates were derived from it. The parameter of interest is the final infiltration rate. However, the cumulative intake rates are presented for completeness. For each waste, the observations for each replicate ring were computed separately and then averaged.

E.6.2.1 Initial Permeability Test

The initial infiltration tests were conducted 1 to 1.5 months after the wastes were emplaced (47 days for the Alliance waste, 30 days for the Georgetown waste). The initial average infiltration rates and cumulative water intake were quite high. At six hours, the average infiltration rate of the Alliance waste had stabilized at 5.0 cm/hr (1.4 x 10^{-3} cm/sec), and the cumulative water intake was 30.0 cm (Table E-26). The final infiltration rate was approaching 4.0 cm/hr (1.1 x 10^{-3} cm/sec).

For the Georgetown waste, the average infiltration rate was 7.1 cm/hr (2.0 x 10^{-3} cm/sec), and the cumulative water intake was 42.4 cm at the end of six hours (Table E-27). The final infiltration rate was approaching 6.0 cm/hr (1.7 x 10^{-3} cm/sec).

The infiltration rates obtained from the initial test of the Georgetown AFBC waste were approximately 40% higher than those obtained from the initial test of the Alliance AFBC waste. This difference is most likely due to physical differences between the two wastes. However, it is also possible that the Alliance waste exhibited lower infiltration due to its longer exposure to the weathering process (47 days versus 30 days).

E.6.2.2 Interim Permeability Test

After 14.5 months, the infiltration characteristics of the Alliance AFBC waste had changed substantially. Over a period of five hours, average values for the infiltration rate and cumulative water intake were 0.4 cm/hr (1.1 x 10^{-4} cm/sec) and 2.0 cm, respectively (Table E-28). The final infiltration rate was 0.4 cm/hr (1.1 x 10^{-4} cm/sec).

TABLE E-26. INITIAL INFILTRATION TEST RESULTS FOR THE ALLIANCE AFBC WASTE

Site 1			Site 2			Average of Sites 1 & 2	
	Intake Rate			Intake Rate			
Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*
1	0.8	48.0	1	0.6	36.0	0.7	42.0
2	1.0	30.0	2	0.8	24.0	0.9	27.0
3	1.2	24.0	3	1.1	22.0	1.2	23.0
5	1.2	14.4	5	1.4	16.8	1.3	15.6
10	1.7	10.2	10	2.4	14.4	2.0	12.3
15	2.0	8.0	15	3.2	12.8	2.6	10.4
20	2.3	6.9	20	3.9	11.7	3.1	9.3
30	2.8	5.6	30	5.3	10.6	4.0	8.1
60	4.5	4.5	60	8.5	8.5	6.5	6.5
90	6.2	4.1	90	12.2	8.1	9.2	6.1
120	7.9	4.0	120	15.4	7.7	11.6	5.8
180	11.6	3.9	180	21.4	7.1	16.5	5.5
240	14.9	3.7	240	27.1	6.8	21.0	5.2
300	17.9	3.6	300	33.7	6.7	25.8	5.2
360	20.5	3.4	360	39.4	6.6	30.0	5.0

* Values were rounded to the nearest tenth.

TABLE E-27. INITIAL INFILTRATION TEST RESULTS FOR GEORGETOWN AFBC WASTE

Site 1			Site 2			Average of Sites 1 & 2	
	Intake Rate			Intake Rate			
Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*
1	0.7	42.0	1	1.0	60.0	0.8	51.0
2	1.0	30.0	2	1.7	51.0	1.4	40.5
3	1.1	22.0	3	2.2	44.0	1.6	33.0
5	1.5	18.0	5	3.1	37.2	2.3	27.6
10	2.4	14.4	10	4.7	28.2	3.6	21.3
15	3.0	12.0	15	5.7	22.8	4.4	17.4
20	3.6	10.8	20	6.7	20.1	5.2	15.4
30	4.8	9.6	30	9.5	19.0	7.2	14.3
60	7.5	7.5	60	14.0	14.0	10.8	10.8
90	10.0	6.7	90	18.8	12.5	14.4	9.6
120	12.5	6.2	120	22.3	11.2	17.4	8.7
180	16.8	5.6	180	30.6	10.2	23.7	7.9
240	21.0	5.2	240	38.6	9.6	29.8	7.4
300	25.1	5.0	300	46.4	9.2	35.8	7.1
360	29.7	5.0	360	55.0	9.2	42.4	7.1

* Values were rounded to the nearest tenth.

TABLE E-28. INTERIM INFILTRATION TEST RESULTS FOR THE ALLIANCE AFBC WASTE

Site 1			Site 2			Average of Sites 1 & 2	
	Intake Rate			Intake Rate			
Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*
1	0	0	1	0	0	0	0
2	0	0	2	0	0	0	0
3	0	0	3	0	0	0	0
5	0.1	1.2	5	0	0	0.05	0.6
10	0.2	1.2	10	0	0	0.1	0.6
15	0.2	0.8	15	0	0	0.1	0.4
20	0.2	0.6	20	0	0	0.1	0.3
30	0.2	0.4	30	0.2	0.4	0.2	0.4
60	0.5	0.5	60	0.3	0.2	0.4	0.4
90	0.6	0.4	90	0.4	0.2	0.5	0.3
120	0.8	0.4	120	0.5	0.2	0.6	0.3
180	1.3	0.4	180	0.9	0.3	1.1	0.4
240	1.8	0.4	240	1.3	0.3	1.6	0.4
300	2.3	0.5	300	1.7	0.3	2.0	0.4

* Values were rounded to the nearest tenth.

Infiltration rates of the Georgetown waste had also decreased since the first measurements, taken 8.5 months earlier. At the end of the second test (approximately five hours), average infiltration rates had stabilized at 0.3 cm/hr (8.3 x 10^{-5} cm/sec) and cumulative water intake was 1.4 cm (Table E-29). The final infiltration rate was approaching 0.3 cm/hr (8.3 x 10^{-5} cm/sec).

Compared to the initial test, the average infiltration rates during the interim test changed very little over the five-hour period. This consistent rate was most likely due to moist or saturated conditions created by a rainfall event which had occurred within 24-hours prior to the interim test. The wastes were approaching their final infiltration capacities when the measurement was taken. For a given test, the final infiltration rate is independent of antecedent conditions. However, the rate at which that final infiltration rate is approached, and hence the average infiltration capacity and cumulative water intake, is dependent on antecedent conditions. Dry materials accept water faster, which leads to higher averages and total intake.

E.6.2.3 Final Permeability Test

The third set of permeameter measurements was made approximately 19 months after emplacement of the Alliance waste and 13 months after emplacement of the Georgetown wastes. Significant changes in the materials were noted over the test period. Both wastes, when emplaced, were slightly moist, friable to powdery, and incoherent. The Alliance waste had become dense (but malleable) with an apparent clay-loam texture or consistency. It was neither friable nor brittle. The Georgetown waste had also become dense and somewhat indurated. The surface of the waste mass was domed, with the center approximately four inches higher than the edges. The infiltration rings were driven and recovered with difficulty.

The final infiltration test on the Alliance waste was inconclusive. The reinforced concrete pipe container had failed in tension and cracked vertically (longitudinally) and opened about four inches. The waste mass

TABLE E-29. INTERIM INFILTRATION TEST RESULTS FOR THE GEORGETOWN AFBC WASTE

Site 1			Site 2			Average of Sites 1 & 2	
	Intake Rate			Intake Rate			
Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)*
1	0	0	1	0	0	0	0
2	0	0	2	0	0	0	0
3	0	0	3	0	0	0	0
5	0	0	5	0	0	0	0
10	0.1	0.6	10	0	0	0.05	0.3
15	0.1	0.4	15	0	0	0.05	0.2
20	0.1	0.3	20	0	0	0.05	0.2
30	0.2	0.4	30	0.1	0.2	0.2	0.3
60	0.3	0.3	60	0.3	0.3	0.3	0.3
90	0.4	0.3	90	0.5	0.3	0.4	
120	0.6	0.3	120	0.6	0.3	0.6	0.3
180	1.0	0.3	180	0.9	0.3	1.0	0.3
240	1.2	0.3	240	1.0	0.2	1.1	0.2
300	1.5	0.3	300	1.3	0.3	1.4	0.3

* Values were rounded to the nearest tenth.

had also developed a radial tension crack extending at least to the center of the permeameter. This crack was directly related to the unloading stress and does not imply a great deal about secondary permeability development. In the normal course of events, the lateral confinement provided by the container walls would have prevented the opening of weathering creacks and other fissures in the waste mass. As the infiltrometer measurements (Table E-30) show, this crack vitiated the final infiltrometer measurements. The entire surface of the permeameter had either been disturbed by previous infiltrometer tests or was occupied or influenced by the crack. The six-hour, final infiltration rates measured for the two rings were 11.6 and 3.0 cm/hr, respectively. The cumulative water intakes were 69.8 and 17.8 cm. In view of the container failure, the rates measured during the interim test were taken as a better measure of the long-term permeability of the waste. The container failure, which probably occurred during the preceding winter (1980-1981), apparently did not affect the interim measurement.

The infiltration capacity of the Georgetown waste had decreased significantly since the wastes were emplaced and since the interim measurements were made. The five-hour average infiltration rate was 0.06 cm/hr (1.7 x 10^{-5} cm/sec) and the cumulative water intake was 0.3 cm (Table E-31). The final infiltration rate was also approaching 0.06 cm/hr (1.7 x 10^{-5} cm/sec). These rates are near the lower limit of reliability of the method.

E.6.2.4 Discussion of Permeability Results

As expected, the two FBC wastes underwent chemical and physical changes over the 13 to 19 months of exposure to the environment. Both changed from a loose, powdery material to a dense, cohesive mass. A domed upper surface of the waste in the Georgetown AFBC permeameter and the container failure of the Alliance AFBC permeameter are evidence of an increase in volume of the wastes.

The permeability of the two wastes also decreased markedly during the course of the study. A summary of the test results is shown in Table E-32.

TABLE E-30. FINAL INFILTRATION TEST RESULTS FOR THE ALLIANCE AFBC WASTE[1]

Site 1			Site 2		
	Intake Rate			Intake Rate	
Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)[2]	Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)[2]
1	1.0	60.0	1	0	0
2	1.5	45.0	2	0.1	3.0
3	2.2	44.0	3	0.1	2.0
5	3.1	37.2	5	0.3	3.6
10	4.6	27.6	10	0.9	5.4
15	6.0	24.0	15	1.1	4.4
20	7.6	22.8	20	1.5	4.4
30	9.7	19.4	30	2.0	4.0
60	14.5	14.5	60	3.0	3.0
90	22.4	14.9	90	3.8	2.5
120	29.1	14.6	120	5.2	2.6
180	41.2	13.7	180	7.0	2.3
240	51.0	12.8	240	9.0	2.2
300	60.8	12.2	300	13.9	2.8
360	69.8	11.6	360	17.8	3.0

[1] Average values not computed because the data are invalidated by the tension crack in the permeameter.

[2] Values were rounded to the nearest tenth.

TABLE E-31. FINAL INFILTRATION TEST RESULTS FOR THE GEORGETOWN AFBC WASTE

Site 1			Site 2			Average of Sites 1 & 2	
	Intake Rate			Intake Rate			
Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)	Elapsed Time (min)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)	Cumulative Intake (cm)	Average Infiltration Rate (cm/hr)
1	0.1	6.0	1	0	0	0.05	3.0
2	0.1	3.0	2	0	0	0.05	1.5
3	0.1	2.0	3	0	0	0.05	1.0
5	0.1	1.2	5	0	0	0.05	0.6
10	0.1	0.6	10	0	0	0.05	0.3
15	0.1	0.4	15	0	0	0.05	0.2
20	0.1	0.3	20	0	0	0.05	0.15
30	0.2	0.4	30	0.1	0.2	0.15	0.3
60	0.2	0.2	60	0.1	0.1	0.15	0.15
90	0.2	0.1	90	0.1	0.07	0.15	0.08
120	0.2	0.1	120	0.1	0.05	0.15	0.08
300	0.3	0.06	300	0.3	0.06	0.3	0.06
1260	1.2	0.06	1260	1.8	0.08	1.5	0.07

The final infiltration rate is taken as a measure of the permeability. The initial permeability of both wastes was within the range of that expected for a sandy loam soil; the final, a silty, clay soil.

TABLE E-32. SUMMARY OF INFILTRATION TEST RESULTS

Infiltration Test	Months Since Emplacement	Final Infiltration Rate (cm/sec)
Initial:		
Alliance	1.5	1.1×10^{-3}
Georgetown	1.0	1.7×10^{-3}
Interim:		
Alliance	15.5	1.1×10^{-4}
Georgetown	9.5	8.3×10^{-5}
Final:		
Alliance	19.5	inconclusive results
Georgetown	13.0	1.7×10^{-5}

As noted earlier, the interim test on the Alliance waste (taken at 15.5 months after emplacement) was used as a measure of the long-term behavior of the waste. The permeability of the Alliance waste was reduced by one order of magnitude over the period of observation. The permeability of the Georgetown AFBC waste, initially some 40% higher than the Alliance, was reduced by two orders of magnitude over the 13-month period of observation.

Nevertheless, it is important to note that the measured infiltration rates, while low, are not within the so-called "impermeable" range. For instance, a clay liner for a hazardous waste landfill should have a permeability of less than 10^{-7} cm/sec, which is two to three orders of magnitude below the rates measured for the FBC wastes.

Inspection of the surface of the two permeameters revealed no development of secondary permeability. The lateral confinement by the reinforced concrete pipe and the relatively short duration of the period of observation

(13 to 19 months) make it unlikely that open weathering cracks would have formed. As noted above, the fissure in the Alliance waste is a tension crack, formed in response to unloading stress after container failure. Its existence does not indicate secondary permeability development. Field cells filled with Alliance waste did not develop weathering cracks over the same time frame.

Results of the test indicate that physical and mechanical weathering of FBC wastes have changed them from a porous material with a rapid infiltration capacity, to a uniform, relatively dense material with a marked decrease in infiltration capacity. No development of secondary permeability was observed, probably because of the confinement afforded by the concrete cylinders.

E.7 Field Cell Coring

At the close of the field studies, core samples were recovered from selected field cells, and the cells were partially exhumed for inspection. The six cells that were sampled are shown on Table E-33. They include the four cells used in the tracer test, which is discussed in Section E.8, below.

TABLE E-33. FIELD CELLS CORED AT THE CONCLUSION OF FIELD SAMPLING

Cell Number	Waste	Medium
2	Exxon PFBC	Shale
3	Exxon PFBC	Till
5	Exxon PFBC	Alluvium
13	Alliance AFBC	Interburden
14	Alliance AFBC	Alluvium
17	Alliance AFBC	Shale

E.7.1 Coring Operations

The cores were recovered with a truck-mounted soil sampling auger rig. The Alliance AFBC waste (Cells 13, 14, and 17) was soft enough to be sampled with a Shelby tube (a thin-walled, steel sampling tube) which was pushed through the waste mass with the rig. The waste mass was dense, but plastic and not indurated. Complete cores of the waste mass were recovered.

The Exxon PFBC waste (Cells 2, 3, and 5) had become indurated over the 27 months that they were in place. A split-spoon sampler was advanced with great difficulty (>100 blows per six inches) through the waste mass. Cores recovered were partially broken and disturbed by the sampling. The entire contents of the spoon were removed and packaged. The media below those wastes had settled during cell operation, but the waste mass had not. The waste had expanded during weathering and bridged against the cell walls, which prevented the waste mass from settling. The result was a six to nine inch gap or void below the waste mass. As the split-spoon was advanced, the hammer blows eventually exceeded the "beam strength" of the waste mass; all the waste below that point (approximately five inches) spalled off; and no sample was recovered. The waste mass in each of the three Exxon PFBC cells behaved similarly. Cell 17 (Alliance AFBC and shale) also apparently had a void below the waste mass.

Samples from the upper disposal medium layer were recovered by direct excavation. Samples from the lower disposal medium layer were recovered by split-spoon sampler. In general, recovery from the lower layer was poor. Samples were recovered from each of the six cells, but only six inches to a foot of material was recovered from the entire layer, which had an original depth of three feet. This was due largely to the incompetent nature of the media.

E.7.2 Field Observations

After the coring operation was completed, the upper disposal medium layer was partially removed and the waste mass inspected. Each cell displayed a prominent doming of the waste mass. The waste at the center of the cell was two to four inches higher than it was at the edges. This was clear evidence of expansion of the waste mass upon weathering.

No weathering cracks were observed in any of the cells. In retrospect, the lateral confinement by the reinforced concrete pipe and the relatively short duration of the test (19 months for the Alliance PFBC waste and 27 months for the Exxon PFBC waste) should have precluded formation of open weathering cracks as was the case for the above-ground permeameters. One horizontal crack was observed in the Exxon PFBC waste in Cell 2 in the wall of the corehole. However, it was a fresh crack, probably formed by spalling under the drop hammer blows.

E.7.3 Laboratory Determinations

The FBC waste cores were returned to the laboratory and submitted for chemical analysis. Intact cores were first subjected to a gamma ray scan (see Section E.8), then extruded and composited for analysis. A description of the samples is contained in Table E-34. Also included in Table E-34 is a description of weathered Georgetown AFBC waste from the large permeameter experiment. After the final infiltrometer measurements were made, a grab sample was recovered from approximately six inches below the surface of the waste mass. X-ray diffraction analyses and solid-sample compositions of the wastes from the field cell cores are given in Appendix C.

E.8 Residence Time (Tracer) Study

A study of leachate residence time was undertaken in an attempt to shed light upon the type of flow occurring in the field cells. The leachate chemistry data indicated that flow in fractures rather than intergranular flow may have been occurring in the cells.

TABLE E-34. DESCRIPTIONS OF CORE SAMPLES OF FBC WASTES FROM FIELD CELLS

Exxon PFBC Cell 3; core interval 1.0'-2.0'; dehydrated sample from middle of core: Poorly sorted, friable, dark grayish brown fine to very fine sand-size (1/2-1/16 mm) particles with ~2-3% white particles (probably $CaSO_4$) ranging in size from ~1/4-2 mm; matrix material contains abundant authigenic carbonate rhombs (calcite-reacts with dilute HCL), black, vitreous particles, reddish yellow translucent grains (unknown) and probably finely disseminated $CaSO_4$.

Alliance AFBC Cell 13; core interval 1.0'-3.5'; about 15" below top of core: Very poorly consolidated, very poorly sorted; dark purplish gray silt to clay size matrix containing variable quantities (generally 5 to 10%) of white grains, ~1/4-2 mm in size and 1-10% aggregrated particles from 1-12 mm in size; material is extremely soft and disaggregates with only slight pressure; no apparent cleavange.

Georgetown AFBC waste; grab sample from large permeameter: Poorly sorted, weakly consolidated, dark charcoal gray matrix composed of very fine sand to silt sized particles (<1/8 mm) and white grains ($CaSO_4$?) ~1/4-1/2 mm in size constituting ~1% of the sample. Concentrations of the probable $CaSO_4$ grains occur in loosely consolidated particles up to 1 cm in size and make up to 10% of the sample. Matrix appears to consist primarily of black vitreous material (coal fines?), fine-grained $CaSO_4$, and some $CaCO_3$ (reacts with HCL).

E.8.1 Experimental Design and Choice of Tracers

In order not to disturb the field cells, radioactive tracers were chosen for the study. Two types of tracers were chosen--conservative and nonconservative. The conservative tracer was chosen for minimal interaction with the disposal medium and waste such that it closely followed the water movement through the field cells. This tracer also had a half-life sufficiently short that water passing through the cells would become innocuous in a very short time. The isotope chosen for the conservative tracer was Br-82, which has a half-life of 35.5 hours.

The nonconservative tracers chosen had substantial interactions with the disposal medium and waste layers. Two alkaline earths, Ca-45 and Sr-85, and one transition metal, Co-60, were chosen.

Solutions of these tracers were applied to the surface of the field cells and allowed to infiltrate. The cells were then irrigated, and the sampling points were monitored for the various tracers. At the conclusion of the field cell experiments, the cells were cored. These cores were scanned with a gamma ray detector and beta-counted to determine the extent of migration of the nonconservative tracers.

E.8.2 Field Collection and Counting of Leachates

The tracer solutions were applied to Cells 2, 5, 14, and 17. These cells were chosen to include two types of disposal media and both Exxon PFBC and Alliance AFBC waste. The two disposal media chosen were shale and alluvium.

After the tracer solutions were allowed to infiltrate, the cells were irrigated with approximately six inches of water. The standpipes leading to the gutter directly below the upper layer of disposal medium were pumped until tracers appeared in the pumped solution. Tracer appeared in Cells 2, 5, and 17, after 4, 7, and 1 liters, respectively. The tracers were detected by a 2 x 2 Na(Tl)I solid scintillation detector coupled with a Ludlum

2100 scaler ratemeter. The samples that first contained tracer were sent back to the laboratory for high resolution gamma ray spectroscopy. The tracers never appeared at the gutter in Cell 14.

After the tracers' presence at the interface between the upper disposal medium layer and the waste was confirmed, samples were collected and monitored at the upper sampling point of the field cells. The volumes collected for Cells 2, 5, and 17 were 113, 63, and 20 liters, respectively. No measurable tracer appeared in any samples from the upper sampling points.

E.8.3 Counting of Cored Samples for Nonconservative Tracers

As noted in Section E.7, selected field cells were cored and sampled at the conclusion of the field studies. The cores of the waste layers from Cells 2, 5, 14, and 17 were returned to the laboratory in mild steel casings or wrapped in plastic. The cores were scanned using a high resolution solid state germanium gamma ray detector. The detector was coupled with a one-cm lead slit. The cores were scanned at five-centimeter intervals. The scans were conducted for 30 minutes each. There were no nonconservative tracers found in any of the cells. It was determined that cores of the upper disposal medium layer would be necessary to determine the extent of nonconservative tracer migration. These upper cores were obtained for Cells 2, 5, and 14 by hammering 1.5-in diameter PVC pipes into the disposal media and extracting the cores. These cores were first scanned with the germanium gamma ray detector with a two-centimeter lead slit every other two-cm segment along the PVC pipe.

The data obtained in these scans are shown in Table E-35 and are graphically displayed in Figures E-10 through E-12. The cores were then extruded and sliced into one-centimeter sections along the length of the core. These one-centimeter sections were homogenized, and a weighed sample was slurried onto a planchette and beta-counted. The beta counter used was a low background Tennelec alpha and beta counter. The data were obtained with five minute counts; these data are compiled in Table E-36 and graphically displayed in Figures E-13 through E-15.

TABLE E-35. GAMMA-RAY SCANS OF FIELD CELLS 2, 5, AND 14 FOR Sr-85 AND Co-60

Depth (cm)	Cell 2		Cell 5		Cell 14	
	Sr-85 (cts/min)	Co-60 (cts/min)	Sr-85 (cts/min)	Co-60 (cts/min)	Sr-85 (cts/min)	Co-60 (cts/min)
0-2	4.1 ± 0.5	0.7 ± 0.2	0	2.1 ± 0.4	0	0
4-6	1.5 ± 0.3	1.6 ± 0.3	1.1 ± 0.3	1.5 ± 0.3	1.6 ± 0.3	0
8-10	20.9 ± 1.1	2.4 ± 0.4	31.9 ± 1.5	3.3 ± 0.5	13.7 ± 1.0	1.9 ± 0.4
12-14	4.9 ± 0.6	1.3 ± 0.3	5.1 ± 0.6	1.5 ± 0.3	4.6 ± 0.6	0
16-18	2.7 ± 0.4	0.07 ± 0.07	6.2 ± 0.6	1.4 ± 0.3	2.6 ± 0.4	0
20-22	5.3 ± 0.6	2.2 ± 0.4	5.1 ± 0.6	0.8 ± 0.2	3.5 ± 0.5	0.5 ± 0.2
24-26	1.0 ± 0.3	0	4.9 ± 0.6	0.9 ± 0.2	7.2 ± 0.7	0
28-30	1.2 + 0.3	0	1.3 + 0.3	0.3 + 0.2	1.9 + 0.4	0

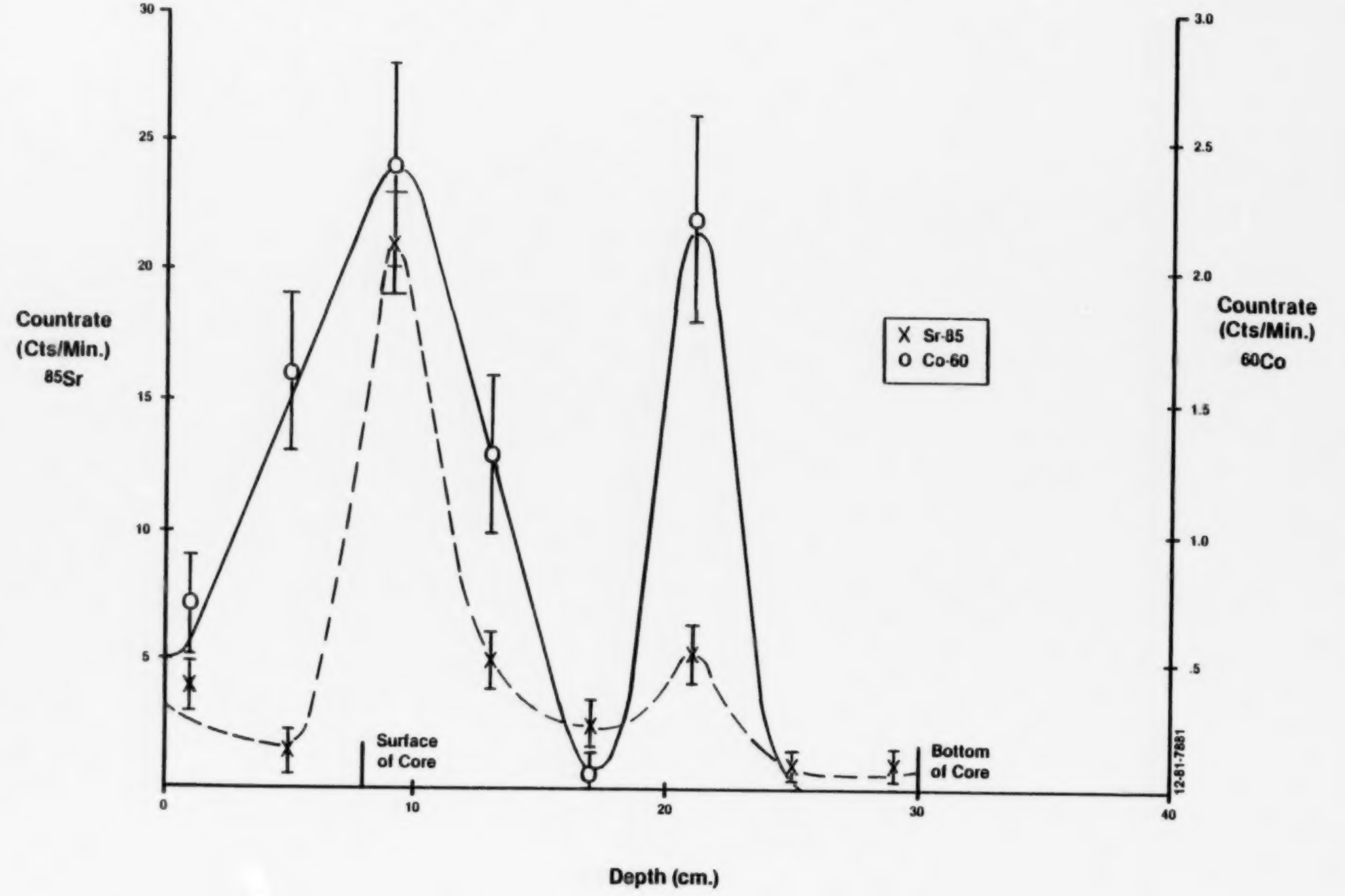


Figure E-10. Gamma-Ray Scan of Field Cell 2 (Exxon PFBC and Shale) for Sr-85 and Co-60.

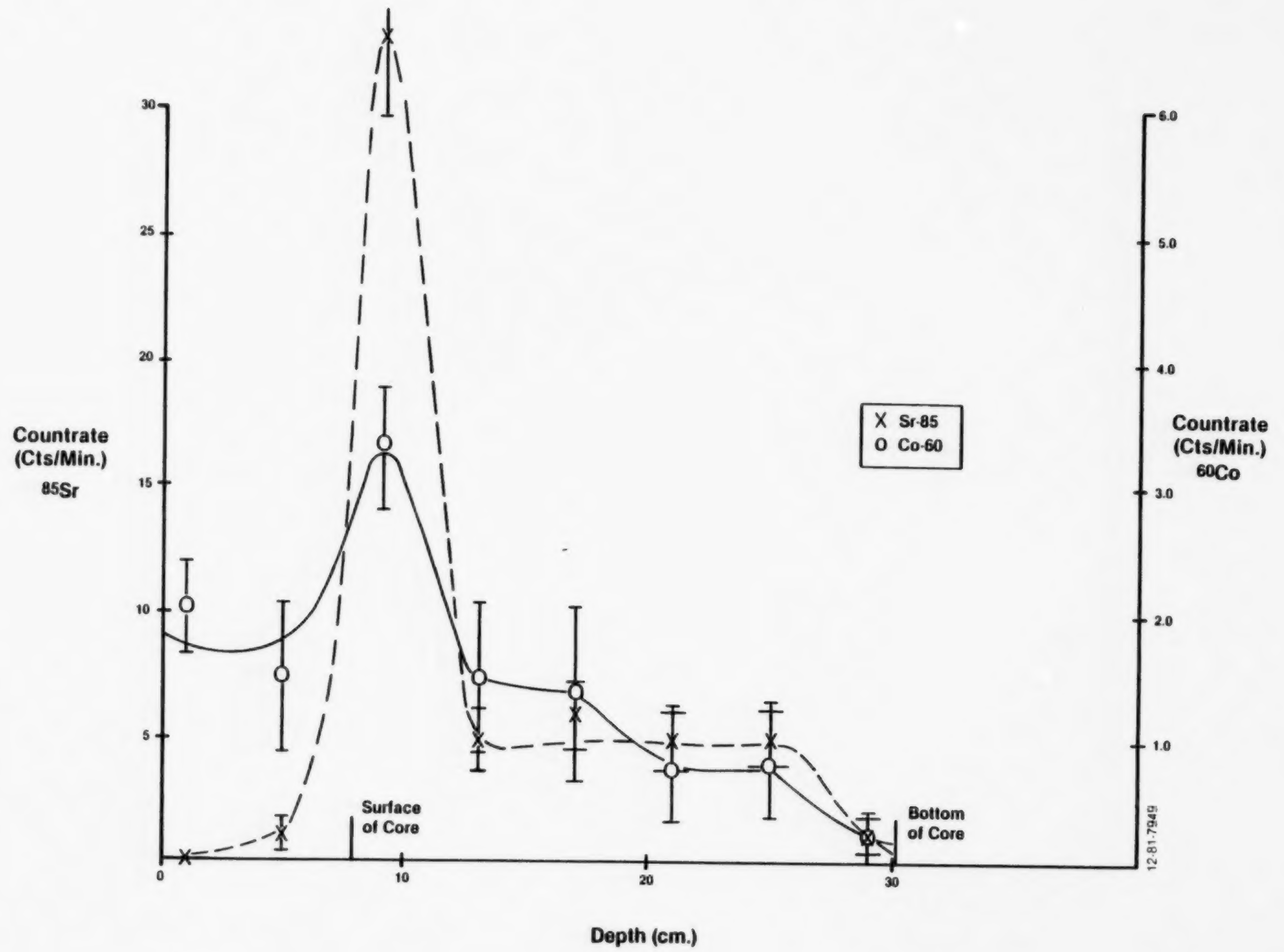


Figure E-11. Gamma-Ray Scan of Field Cell 5 (Exxon PFBC and Alluvium) for Sr-85 and Co-60.

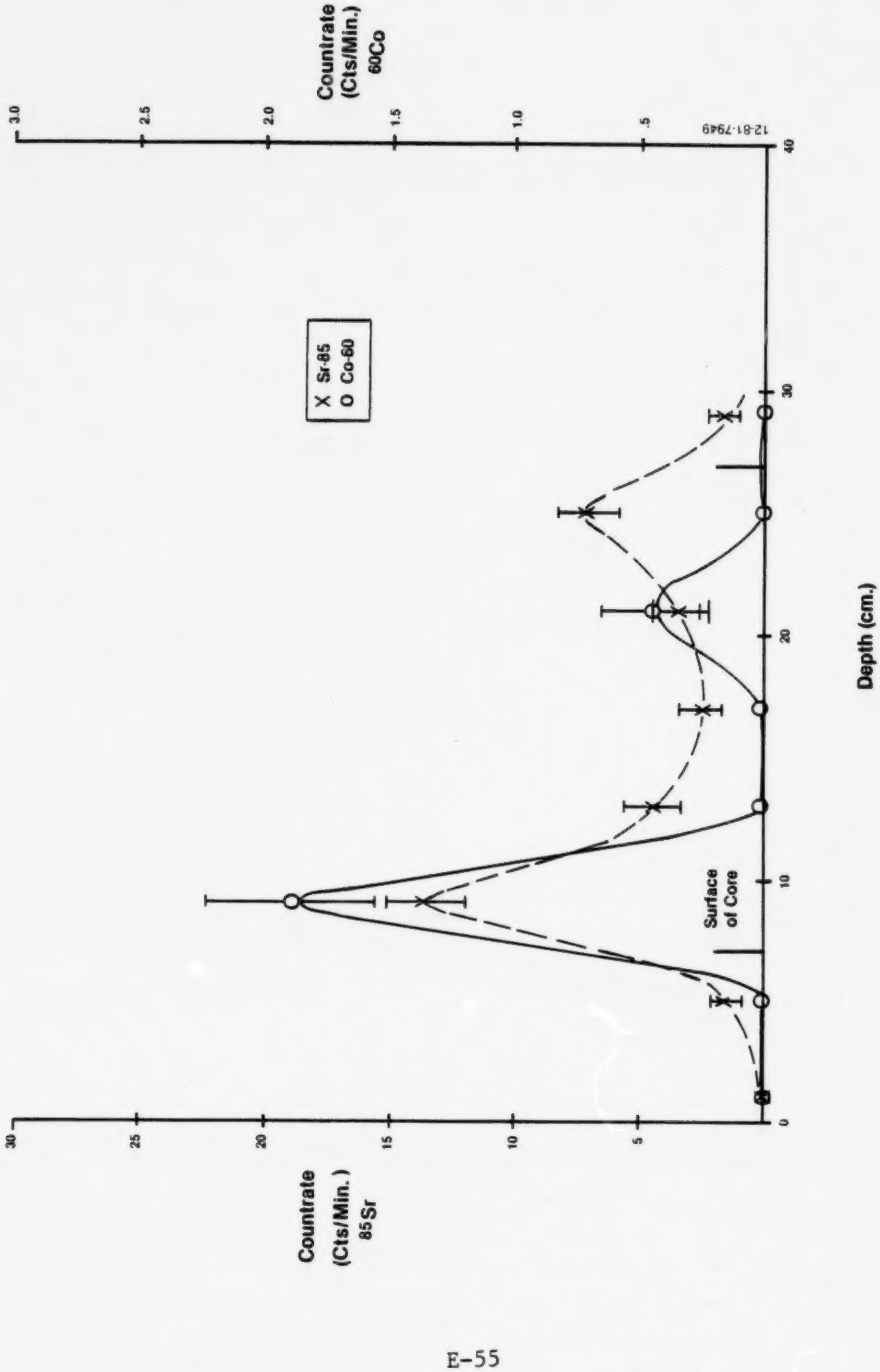


Figure E-12. Gamma-Ray Scan of Field Cell 14 (Alliance AFBC and Alluvium) for Sr-85 and Co-60.

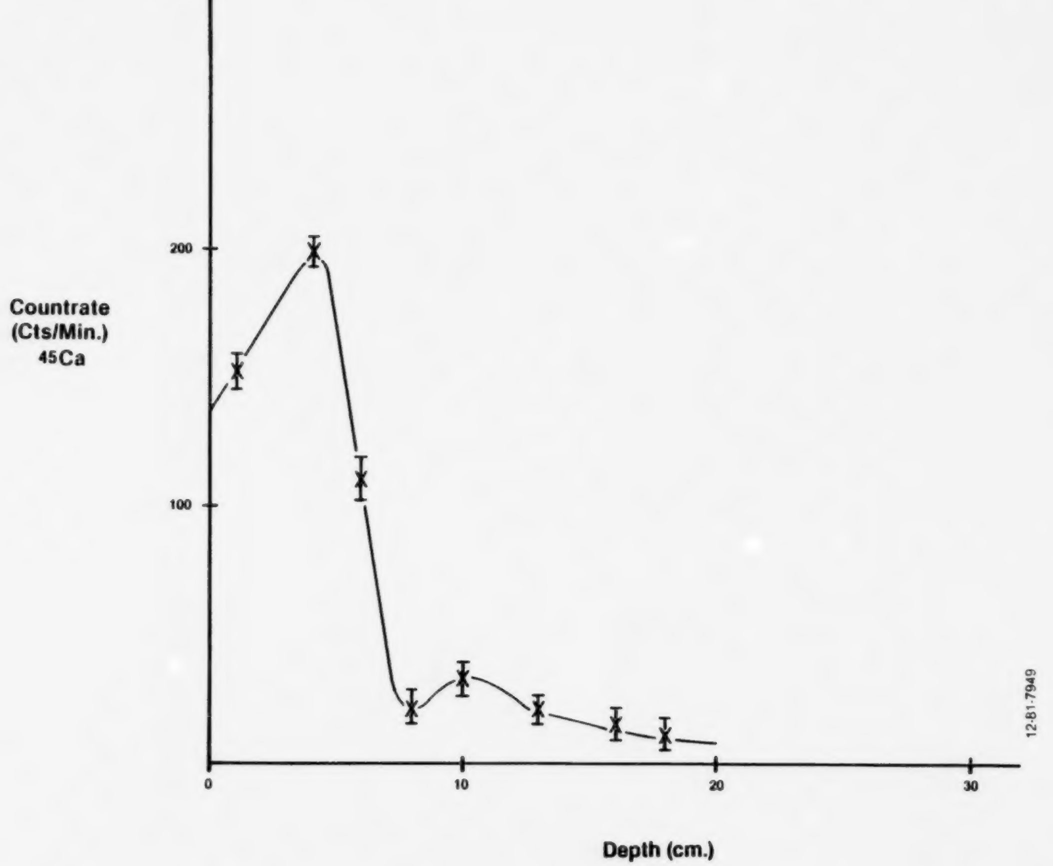


Figure E-13. Beta-Scan of Field Cell 2 (Exxon PFBC and Shale) for Ca-45.

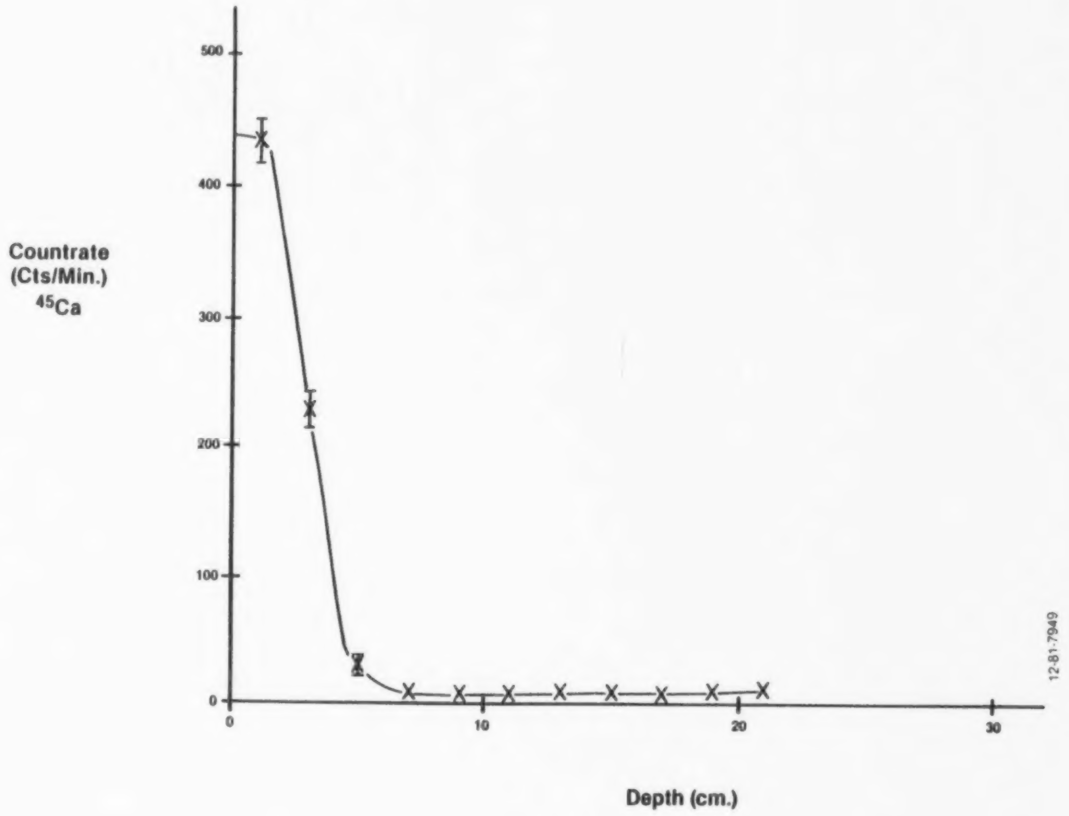


Figure E-14. Beta-Scan of Field Cell 5 (Exxon PFBC and Alluvium) for Ca-45.

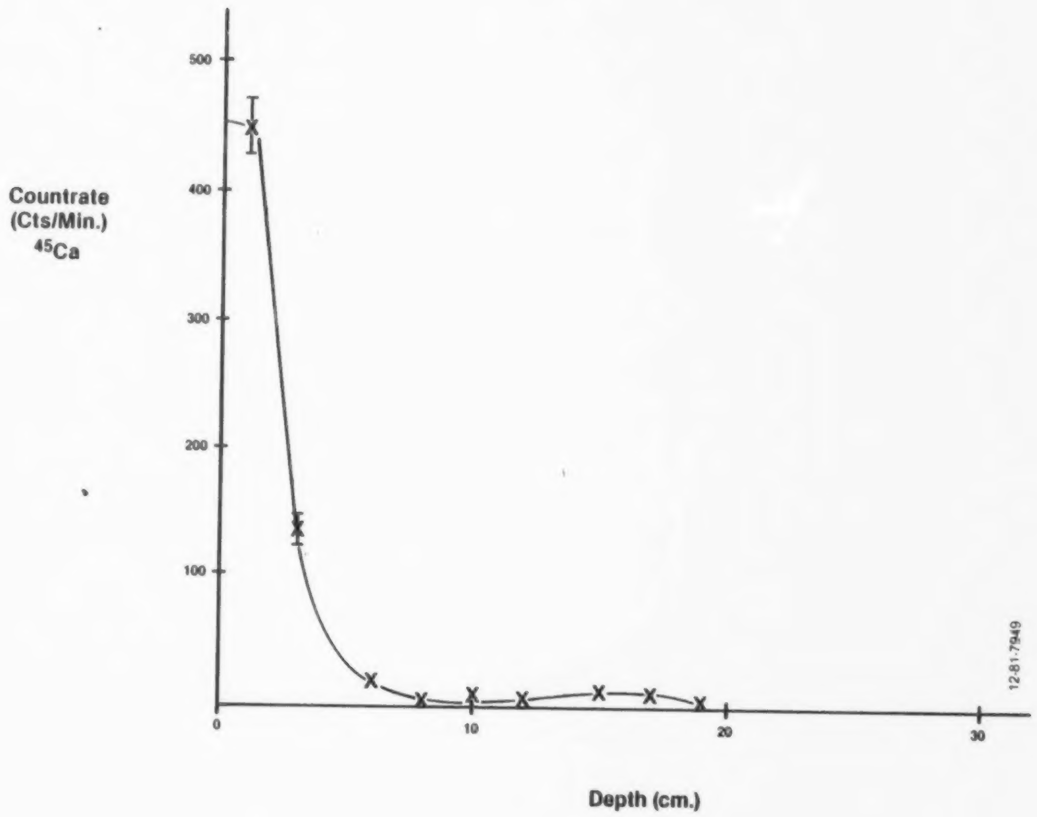


Figure E-15. Beta-Scan of Field Cell 14 (Alliance AFBC and Alluvium) for Ca-45.

TABLE E-36. BETA SCANS OF FIELD CELLS 2, 5, AND 14 FOR Ca-45

Cell 2		Cell 5		Cell 14	
Depth (cm)	Count Rate (cts/min)	Depth (cm)	Count Rate (cts/min)	Depth (cm)	Count Rate (cts/min)
0-1	153.6 ± 5.5	0-1	437.5 ± 9.4	0-1	450.8 ± 9.5
4-5	198.4 ± 6.3	2-3	233.4 ± 6.8	2-3	137.4 ± 5.2
6-7	109.0 ± 4.7	4-5	30.6 ± 2.5	4-5	19.6 ± 2.0
8-9	23.4 ± 2.2	6-7	11.6 ± 1.5	6-7	8.0 ± 1.3
10-11	33.4 ± 2.6	8-9	8.0 ± 1.3	8-9	9.6 ± 1.4
13-14	22.6 ± 2.1	10-11	8.4 ± 1.3	10-11	9.4 ± 1.4
16-17	15.8 ± 1.8	12-13	8.2 ± 1.3	13-14	12.2 ± 1.6
18-19	11.6 + 1.5	14-15	8.6 ± 1.3	15-16	11.0 ± 1.5
		16-17	9.2 ± 1.4	18-19	7.8 ± 1.2
		17-18	8.8 ± 1.3		
		19-20	11.6 ± 1.5		

E.8.4 Tracer Study Results

The results of tracer breakthrough observed in Cells 2, 5, and 17 of 4, 7, and 1 liters, respectively, at the gutter directly below the upper disposal media indicated that some channelling occurred because of the rapid pumping velocity employed. This is quite evident since with a porosity of 20%, the pore volume should be 70 liters.

The 113 L volume of leachate collected at the upper sampling point in Cell 2 indicated that fissure flow through the waste does not exist, in contrast to the case of the upper disposal medium in which breakthrough occurred at volumes much lower than the theoretical pore volume. The theoretical pore volumes for the waste are 106 and 214 liters at 20 and 40% porosity, respectively. The observed leachate volume without tracer breakthrough indicates that the real pore volume is at least greater than 21.3 percent. This result indicates that porous (intergranular) flow exists in the cells.

The gamma ray scans conducted on the cores obtained from the upper disposal media exhibited unusual migration behavior. The first unusual behavior was the of two distinct maxima in tracer concentration in Cells 2 and 14. The first maximum is found in the first four centimeters of the core near the surface. The second appears at a depth of between 13 and 19 centimeters. The peaks appear for both Sr-85 and Co-60. These double peaks possibly are present also in the Ca-45 scans, but statistically are not very significant in comparison. These double peaks do not exist in data for Cell 5. The two peaks imply two chemical species; however, since Cells 5 and 14 have the same disposal medium, it is difficult to explain their differing behavior. Determination of the cause of this phenomenon would require further study under more controlled conditions. The only general conclusion that can be drawn is that the majority of the tracers added (>70%) migrated very slowly and stayed in the top four centimeters of the disposal media. A small portion of the tracer, however, unexplicably migrated rather rapidly to a depth of 13 to 19 centimeters.

E.9 Leachate Generation and Attenuation in the Field Cells

The analytical results for leachates from the six Exxon PFBC waste cells (Cells 1 to 6), the five Alliance AFBC waste cells (Cells 13 to 17), and the two media control cells (Cells 7 and 12) are contained in Appendix J. Conceptually, the upper sampling point of the field cells corresponds to Steps 1, 2, and 3 in the laboratory protocol (except that the leaching fluid has contacted the upper soil layer first), and the lower sampling point corresponds to Steps 4, 5, and 6 of the laboratory protocol. Independent of the similarity or difference between laboratory and field results, the field cell data are also examined solely in terms of FBC waste behavior under the simulated landfill conditions. The field data represent pilot scale studies and come closer to simulating full scale landfill behavior than laboratory data.

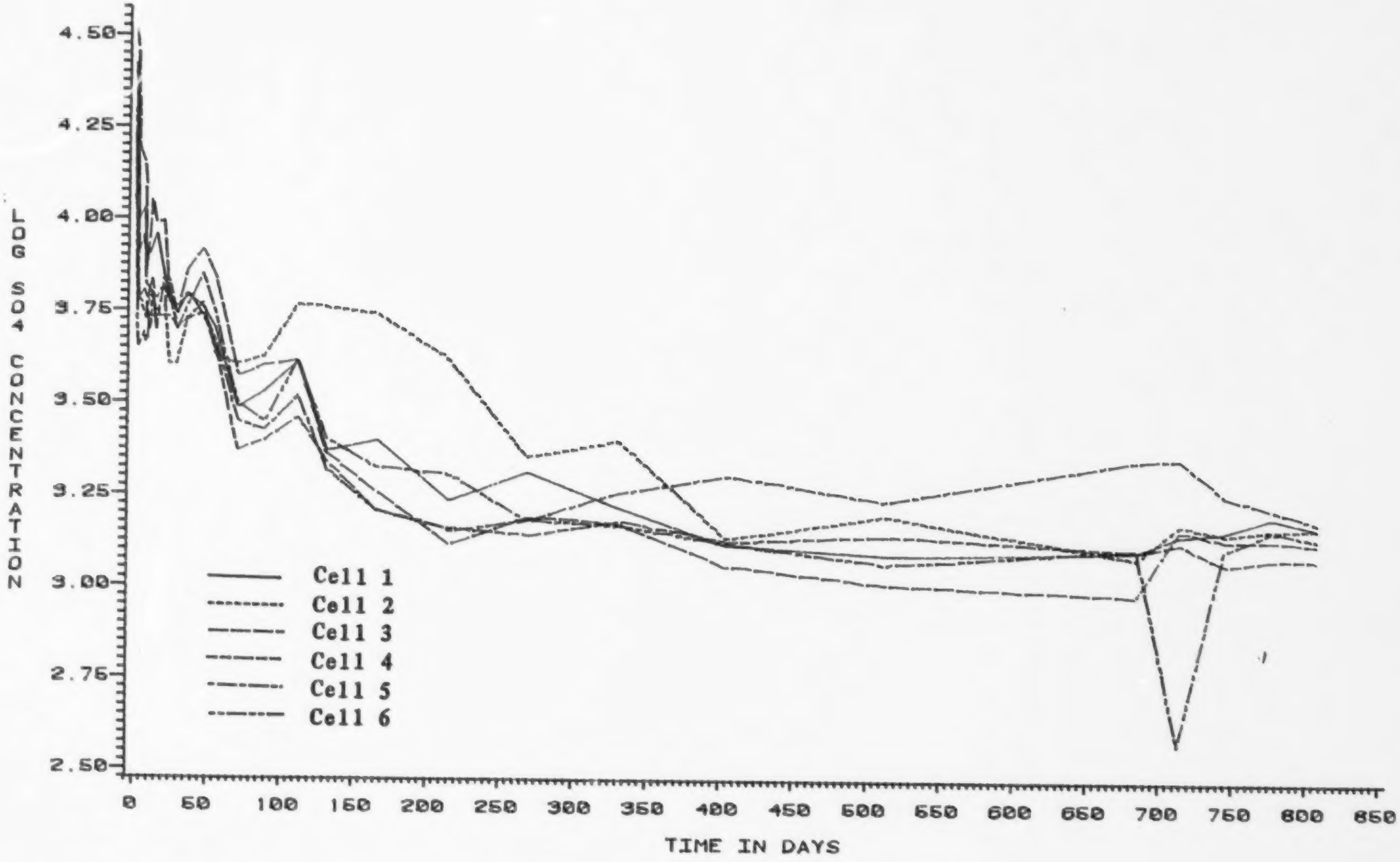
E.9.1 Upper Sampling Point (Leaching) Results

E.9.1.1 Time Series Behavior of the Exxon PFBC Field Cells

To facilitate visualization of concentration trends with time, computer plots were generated for $\log_{10}$ of the species concentration as a function of the number of days the field cells were in operation. The log of the concentration was used to facilitate use of the Y axis since concentration ranges were extremely large in many cases. Examination of the plots showed very high concentrations for many of the species in the early eluant volumes from the Exxon PFBC field cells. In some cases, these early samples were characterized by wide oscillations downward after initially high concentrations followed by increasing concentrations again.

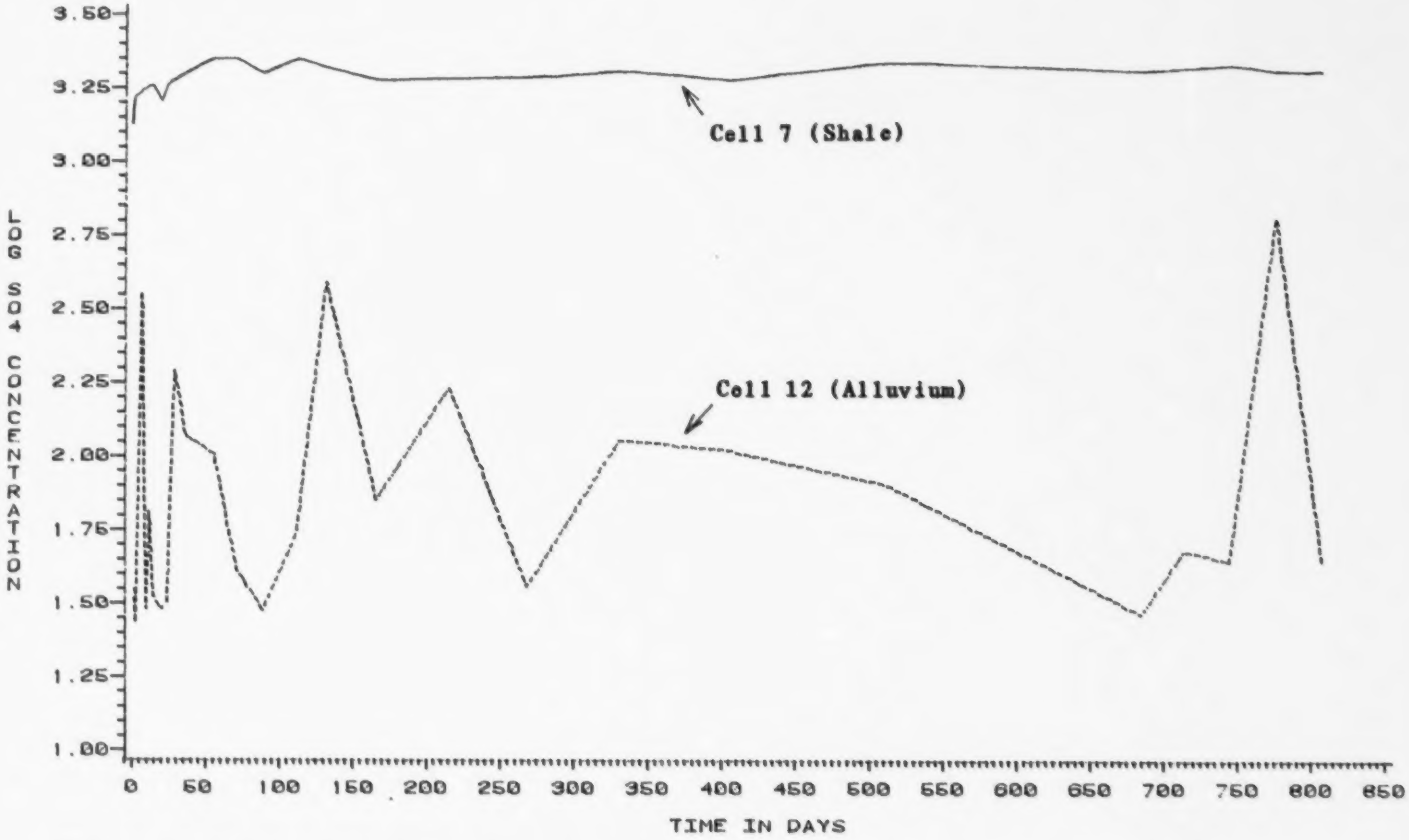
These high concentrations and fluctuations typically occurred over the first month of operation. In this time, the volume-per-mass ratio for the samples withdrawn was extremely small. Very high concentrations of the most soluble species from both the overlying disposal medium layer and the waste material would be expected in the leachate. Sodium and potassium ions are easily concentrated, and any sulfate associated with these cations would be readily dissolved. Solubility of other ions would be enhanced, even if thermodynamically controlled, by the high ionic strength of the early leachate.

Figure E-16 presents the sulfate concentration trends for the upper sampling point of the six Exxon PFBC field cells. Data for the shale and alluvium field control columns (Figure E-17) show that the upper soil layer could not have been the principal source of the sulfate ion in the cells containing waste. Correspondingly high sodium (Figure E-18) and potassium (Figure E-19) were found during the early elution period. Specific conductance and total dissolved solids paralleled the sulfate, sodium and potassium data. Calcium values (Figure E-20) were suppressed in the early elution volumes relative to later concentrations, likely as a result of the common ion effect on solubility equilibrium with calcium sulfate. Similar behavior is seen for barium concentration, as would be expected.



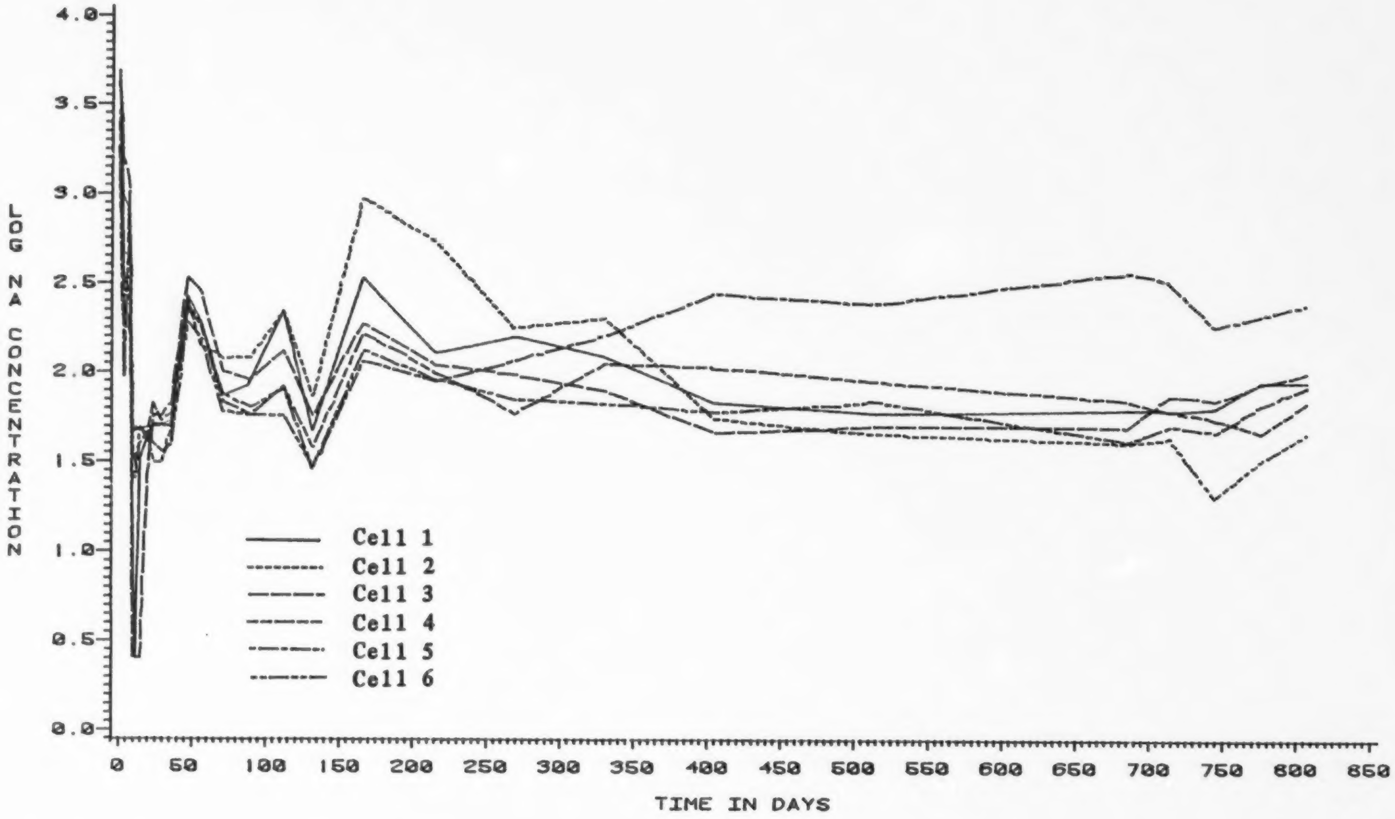
NOTE: DETECTION LIMIT VALUES ARE SET TO ONE HALF DETECTION LIMIT

Figure E-16. Sulfate Concentration Trends (mg/L) for Leachates from the Upper Sample Point of the Exxon PFBC Field Cells.



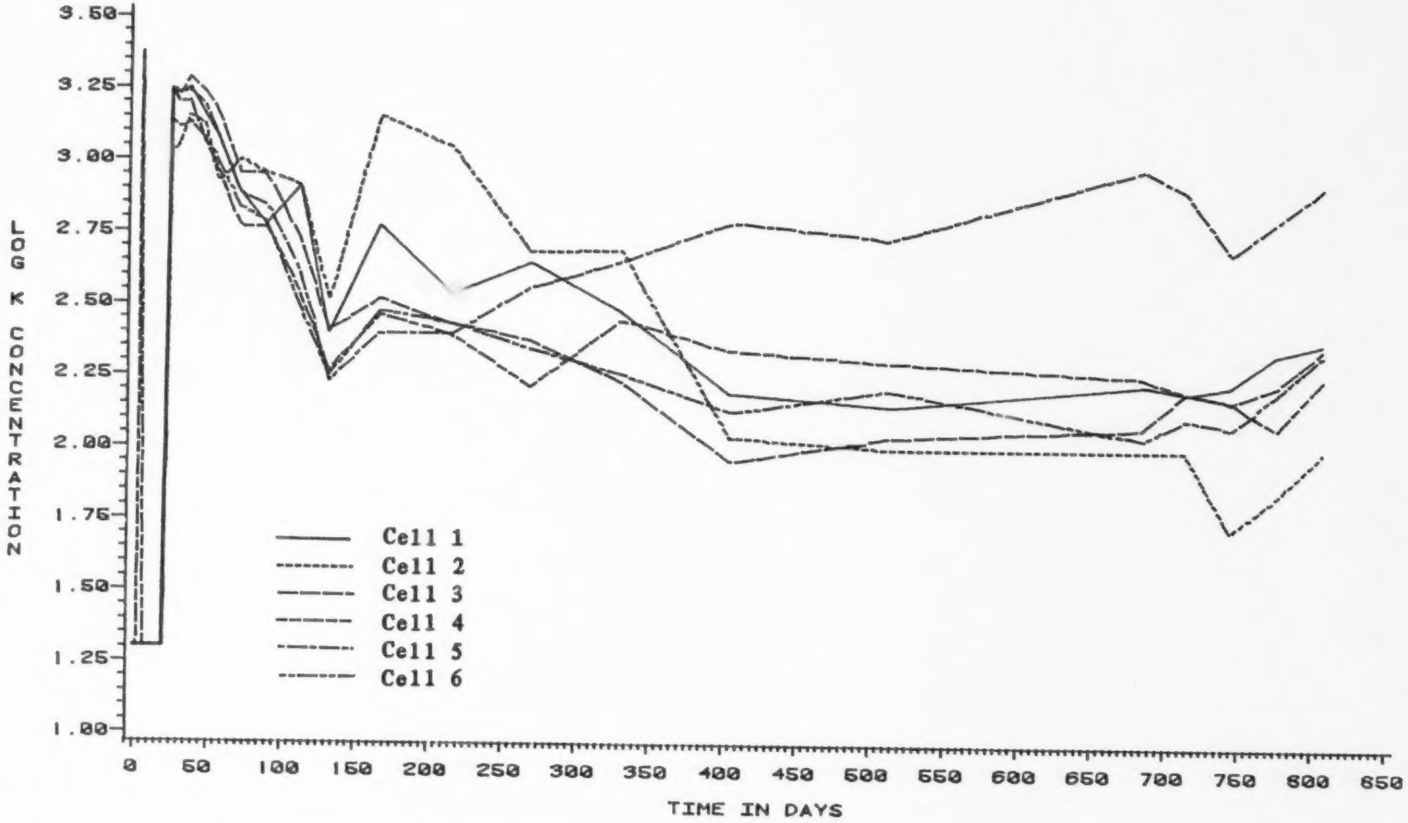
NOTE: DETECTION LIMIT VALUES ARE SET
TO ONE HALF DETECTION LIMIT

Figure E-17. Sulfate Concentration Trends (mg/L) for Leachates from the Control (Media Only) Field Cells.



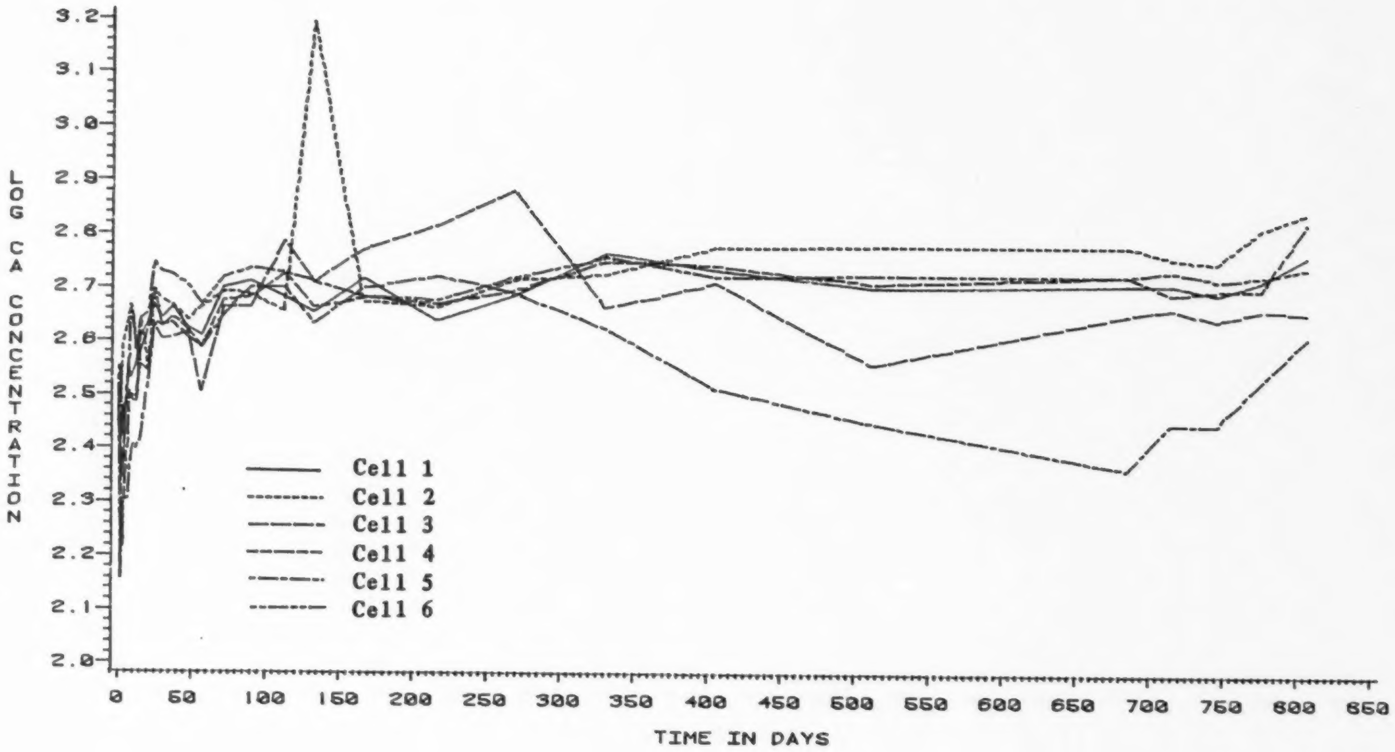
NOTE: DETECTION LIMIT VALUES ARE SET TO ONE HALF DETECTION LIMIT

Figure E-18. Sodium Concentration Trends (mg/L) for Leachates from the Upper Sample Point of the Exxon PFBC Field Cells.



NOTE: DETECTION LIMIT VALUES ARE SET TO ONE HALF DETECTION LIMIT

Figure E-19. Potassium Concentration Trends (mg/L) for Leachates from the Upper Sample Point of the Exxon PFBC Field Cells.



NOTE: DETECTION LIMIT VALUES ARE SET TO ONE HALF DETECTION LIMIT

Figure E-20. Calcium Concentration Trends (mg/L) for Leachates from the Upper Sample Point of the Exxon PFBC Field Cells.

Table E-37 summarizes for each field cell the behavior of other species during the first twenty or so days of cell operation. Some species were elevated in concentration for all field cells during the initial column flushing. Several were not increased appreciably and others showed variation among the field cells. In some cases, pH may have had an influence, such as for the magnesium values for Cells 5 and 6. The initial eluant pH was high for several days for these two cells. The corresponding magnesium values were quite low and increased later as pH decreased. Magnesium hydroxide solubility limited the magnesium concentration while calcium, barium and manganese concentrations increased with elution time.

For some of the constituents, notably Cu, Cd, Cr, and Co, among others, the initial values were high only in a relative sense to the later values which were very low or at detection limits. The soluble form(s) of these species were likely present in very limited quantities and were rapidly flushed from the cells.

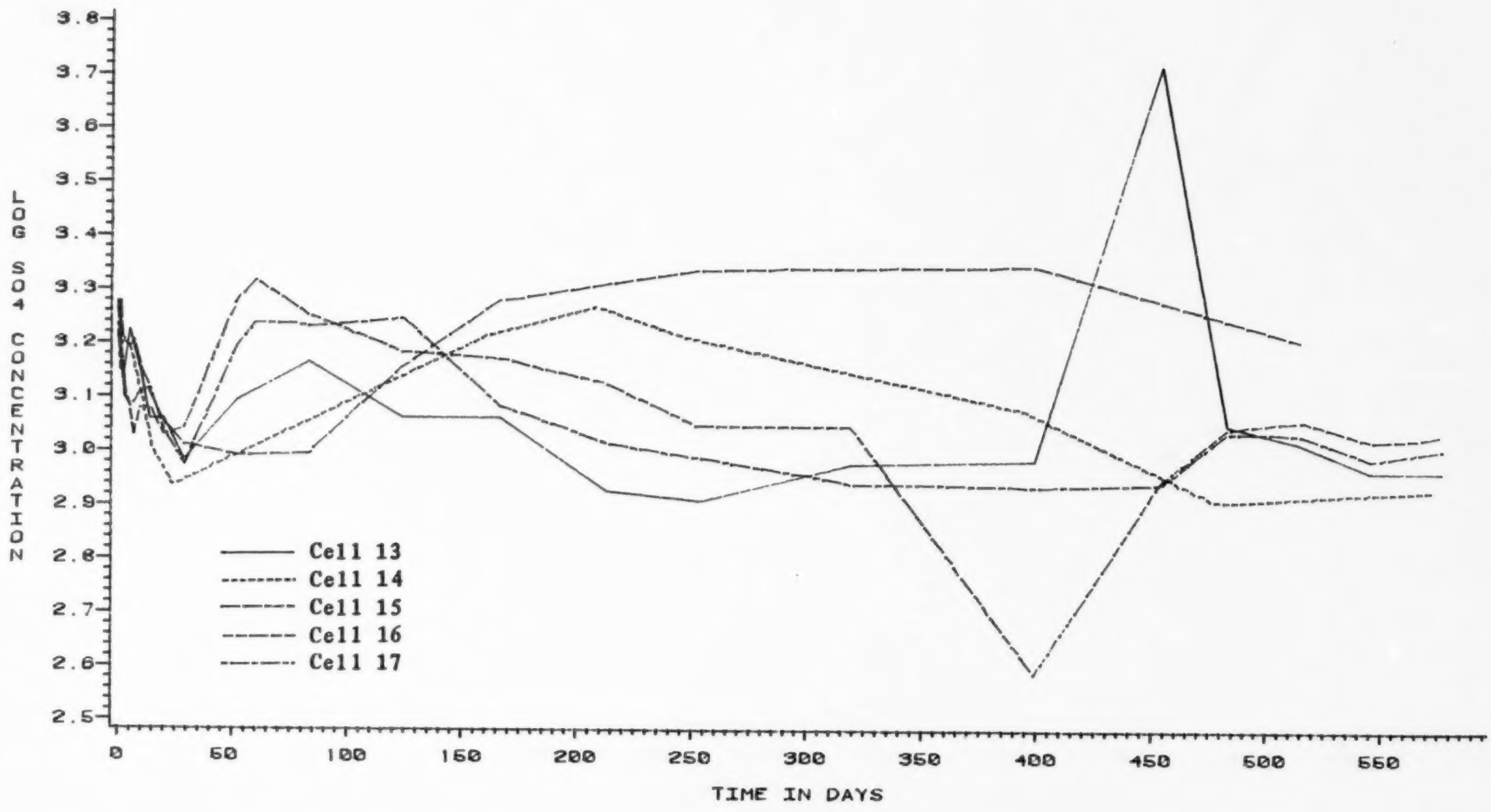
E.9.1.2 Time Series Behavior of the Alliance AFBC Field Cells

Unlike the Exxon PFBC field cells, early elution volumes from the Alliance AFBC field cells (Cells 13 to 17) at the upper sampling point did not generally contain extremely high sulfates. This was in spite of quite low calcium concentrations in the first 20 days (up to 60 days for some cells). Figures E-21 and E-22 present the data for sulfate and calcium, respectively. A qualitative summary of concentration behavior in the early elution period (first 20-30 days) is provided in Table E-38. For some species, the early concentrations were modestly higher than later concentrations and probably reflect rapid mobilization of the total soluble component for the species. Of those species showing this behavior, drops in concentration to detection limit values occurred for several at 50 to 60 days rather than 20 to 30 days. Cr, Cu, Tr, and V were among the species that declined to low values.

TABLE E-37. EXXON PFBC FIELD CELL ELUTION (UPPER SAMPLE POINT) CONCENTRATION BEHAVIOR FOR THE FIRST 20-30 DAYS OF OPERATION

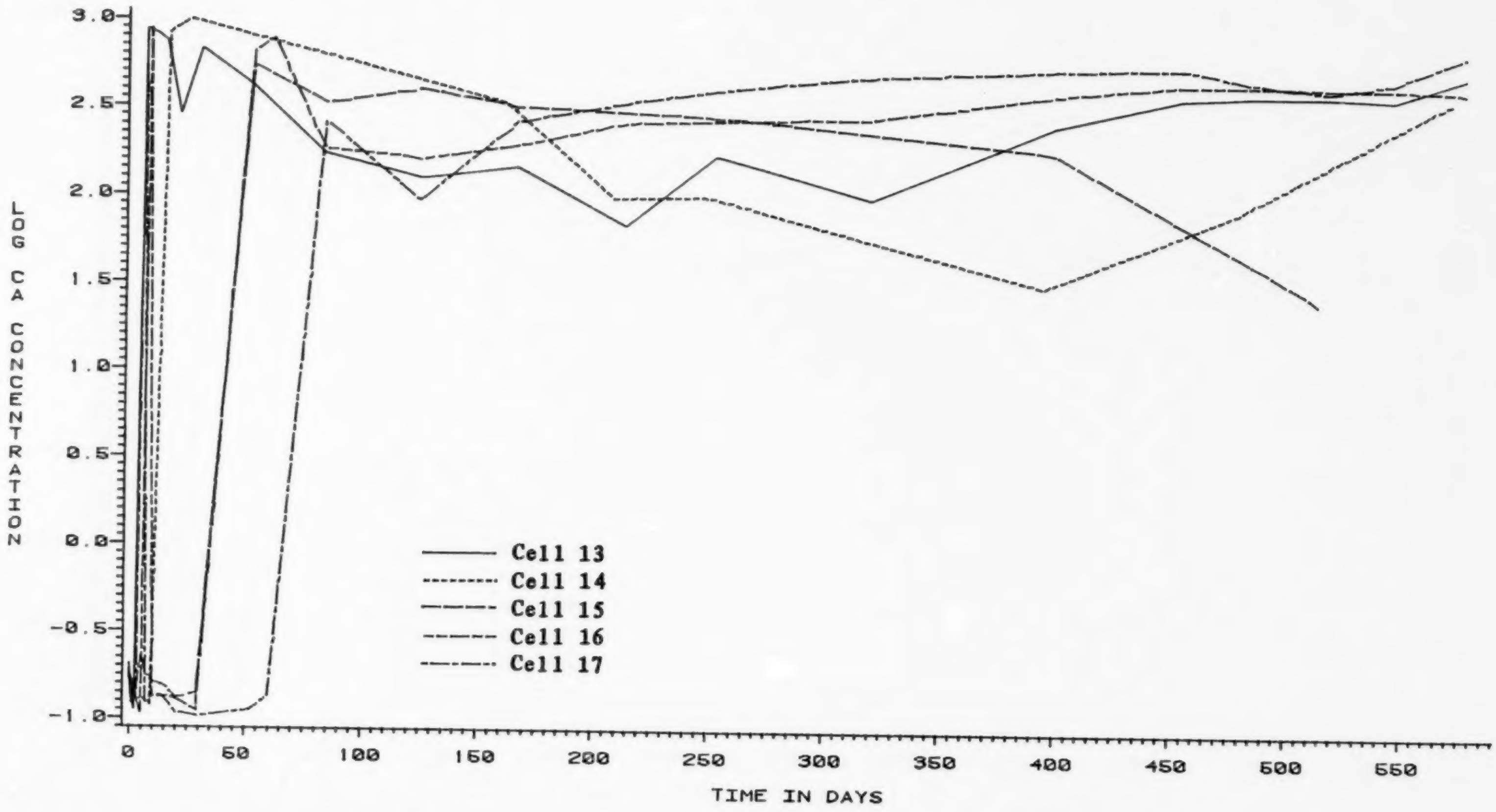
Element/ Species	Cell 1 Shale	Cell 2 Shale	Cell 3 Glacial Till	Cell 4 Limestone	Cell 5 Alluvium	Cell 6 Sandstone
Al	Y	N	N	N	N	N
B	Y	Y	Y	Y	M	Y
Ba	I	I	I	I	I	I
Ca	I	I	I	I	I	I
Cd	Y	N	Y	Y	N	N
Cl	Y	Y	Y	Y	Y	Y
Co	Y	Y	Y	N	N	N
Cr	Y	Y	Y	Y	Y	Y
Cu	Y	Y	Y	N	Y	N
F	M	M	M	M	M	M
Fe	N	N	N	N	N	N
K	(Y)[1]	(Y)[1]	(Y)[1]	(Y)[1]	(Y)[1]	(Y)[1]
Mg	Y	Y	Y	Y	N	N
Mn	I	I	I	I	I	I
Mo	Y	Y	Y	Y	Y	Y
Na	Y	Y	Y	Y	Y	Y
Ni	N	N	N	N	N	N
pH	N	N	N	N	Y[2]	Y[2]
Si	N	N	N	N	N	N
SO_4	Y	Y	Y	Y	Y	Y
Sp.Cond.	Y	Y	Y	Y	Y	Y
Sr	N	N	N	N	N	N
TDS	Y	Y	Y	Y	Y	Y
Ti	N	N	N	N	N	N
V	N	N	N	N	M	N
Zn	Y	N	Y	M	I	N

Y = Yes, early concentrations high (early concentrations are a factor of 4 to 5 or greater than later concentrations).
N = No, early concentrations not higher.
M = Modest (factor of 2 to 3 higher).
I = Inverse, early concentration was low and then increased.
[1] = Post day 20 (since early data at DL not considered reliable).
[2] = Significant pH drop (since pH is log base, factor of 4 to 5 not considered).



NOTE: DETECTION LIMIT VALUES ARE SET TO ONE HALF DETECTION LIMIT

Figure E-21. Sulfate Concentration Trends (mg/L) for Leachates from the Upper Sample Point of the Alliance AFBC Field Cells.



NOTE: DETECTION LIMIT VALUES ARE SET
TO ONE HALF DETECTION LIMIT

Figure E-22. Calcium Concentration Trends (mg/L) for Leachates from the Upper Sample Point of the Alliance AFBC Field Cells.

TABLE E-38. ALLIANCE AFBC FIELD CELL ELUTION (UPPER SAMPLE POINT) CONCENTRATION BEHAVIOR FOR THE FIRST 20-30 DAYS OF OPERATION

Element/ Species	Cell 13 Interburden	Cell 14 Alluvium	Cell 15 Alluvium	Cell 16 Limestone	Cell 17 Shale
Al	M	Y	Y	Y	Y
Ba	Y	M	N	N	N
B	N	N	N	N	N
Cd	DL	DL	DL	DL	DL
Ca	I	I	I	I	I
Cl	M	Y	Y	M	Y
Cr[1]	Y	Y	Y	Y	Y
Co	DL	DL	DL	DL	DL
Cu	Y	Y	Y	Y	Y
F	N	N	N	N	N
Fe	N	N	M	N	N
K	N	N	N	N	N
Li	N	N	N	N	N
Mg	N	N	N	N	N
Mn	I	I	N	I	I
Mo	N	N	N	N	N
Na	N	M	M	N	N
Ni	N	N	N	N	N
pH	Y	N	Y	Y	Y
Si	N	N	I	I	I
SO_4	N	M	N	N	N
Sp.Cond.	M	M	M	M	M
Sr	N	N	M	M	N
TDS	M	M	M	M	M
Ti	Y	Y	DL	DL	Y
V	Y	Y	Y	DL	M
Zn	DL	M	DL	DL	DL

Y = Yes, early concentrations high (early concentrations are a factor of 4 to 5 or greater than later concentrations).
N = No, early concentrations not higher.
M = Modest (factor of 2 to 3 higher).
I = Inverse, early concentration was low and then increased.
DL = At or near detection limit.
[1] = Declines seen at ≥60 days for Cr.

Specific conductance and TDS, measures of the eluant ionic strength, both decreased steadily with time. Initial values were not extraordinarily high, however. While initial chloride levels were high and decreased with time, sodium and potassium did not change appreciably with elution volume.

In four of the five cells, effluent pH was initially high (11+ to 12+) and leachates from the remaining cells had excursions to high pH at later time. The high pH likely influenced the mobility of numerous other species. Magnesium most likely was maintained at low values at high pH but a subsequent appreciable increase in magnesium concentration was not seen when pH decreased. Manganese concentrations increased with increased eluant volume which might relate to the pH variation. Similar speculation could be made regarding the decrease in concentration for other metals (like copper and chromium) with a decrease in pH because of amphoteric behavior. However, actual behavior is likely more complex. For example, the low calcium concentration could be attributed to high carbonate in conjunction with the high pH in the early eluant. As the pH dropped, either total carbonate dropped or $CaCO_3$ solubility increased with shift in solution carbonate equilibrium ($CO_3^{-2} \leftrightarrows HCO_3^-$). Related to this behavior is the possibility that copper was solubilized in the early eluant by the formation of the uncharged complex, $CuCO_3^o$, in solution.

E.9.1.3 Comparison of the Two Wastes and Soil Control Columns

The early elution period from the field columns is a period of transition and instability in individual species concentrations. For a given waste, not all species behaved the same for each cell during this early transition period, although there was usually a general trend for the majority of the cells. Comparison of the Exxon field cell set with the Alliance field cell set does not yield a definitive difference in behavior pattern. The former set had extremely high initial concentrations for a number of species while the latter did not, although some modest initial concentration elevation was seen. Some species did have similar concentration trends for both sets of cells but others did not. Perhaps the difference resided in differences in the pH conditions in the two sets of cells.

Different compound content, different surface chemistry, different fluid flow patterns and accompanying secondary precipitate formation cannot be discounted either.

Table E-39 summarizes comparisons of the concentration ranges for the Exxon and Alliance field cell sets, for the field cells containing wastes and the two field control columns, and for the field cells containing wastes and the laboratory media leach columns. The last three laboratory column sample values and field values for 17 July, 17 August, and 17 September 1981 were used for the comparison. Comparisons with the interburden results are not included. The interburden is highly acidic and atypical relative to the other media examined. Additional comparisons of these concentration ranges are given in Appendix I.

For most species, roughly the same range of values is seen between the Exxon PFBC and Alliance AFBC field cell sets. Variations between the cells for each waste are frequently greater than between the two sets. A few notable differences are apparent. The Exxon PFBC leachate had higher B, Ca, SO_4, and Zn level while the Alliance AFBC waste generated higher Cl, Li, Mn, K, and Sr concentrations. In some instances, the differences were an order of magnitude or more.

Of interest is the result of comparison of waste leachate levels with leachates from the various disposal media. The field control cells were generally mirrored in behavior by the shale and alluvium laboratory control columns. Thus, it would be reasonable to expect the laboratory control columns for the other four disposal media to be reasonable estimators of what their field behaviors would be.

Many species were present at similar or lower concentrations in the leachates from field cells compared to the leachates from disposal media (excluding the interburden). Some dependency on the particular soil was shown. For example, higher calcium values were leached from the sandstone

TABLE E-39. COMPARISON OF CONCENTRATIONS FOR SAMPLING DATES 7/17/81, 8/17/81 AND 9/17/81 FOR FIELD CELLS AND FOR LAST THREE SAMPLES FOR LAB CONTROL COLUMNS

Element/ Species	Comparison of Exxon PFBC to Alliance AFBC Field Cells	Comparison of Field Cells with Wastes to Control Field Cells	Comparison of Field Cells with Waste to Lab Control Columns
Al	Comparable	Shale higher	Comparable
B	Exxon higher	Shale = Exxon	Columns lower than others
Ba	Comparable	Comparable	Columns all lower
Ca	Exxon higher	Shale = Exxon Alluvium ~ Alliance	Covers the range of waste values (V)[2]
Cd	All DL[1]	All DL	All DL
Cl	Alliance much higher (~10X)	Less than Exxon	Much lower than waste (Exxon)
Co	Comparable - DL	Near or = DL	DL
Cr	Comparable	Comparable	Comparable
Cu	Comparable (V)	Comparable (V)	Comparable
F	Comparable	Shale comparable, alluvium less	Some lower, some higher
Fe	Comparable	Shale comparable, alluvium = DL	Soils higher
K	High variability Alliance tends to higher values	Shale low and alluvium very low	Soils much lower, especially alluvium
Li	Alliance higher (2-10X) (V)	Controls much less than wastes	Soils lower
Mg	Comparable	Shale much higher; alluvium comparable	Higher to much higher except alluvium
Mn	Highly variable Alliance higher on one	Shale = DL Alluvium ~ Alliance	Covers same range but some soils higher
Mo	Same range	Same range, alluvium slightly lower	Comparable except limestone higher
Na	Scatter-Comparable on the average	Controls much lower	Columns much lower
Ni	Comparable - low	Comparable - low	Comparable
pH	Comparable	Comparable, alluvium slightly lower	Similar except alluvium slightly lower
Si	Comparable	Controls generally lower by factor of 2 to 3	Comparable to lower
SO_4	Alliance slightly lower	Shale higher, alluvium much lower	Variable (2>, 3<)
Sp. Cond.	Alliance slightly lower	Shale = Exxon Alluvium much lower	Compares to field controls (V)
Sr	Alliance mugh higher (20-30X)	Shale ~ Exxon, alluvium much lower	Exxon equal or less; Alliance greater
TDS	Comparable	Shale ~ waste, alluvium much lower	Variable (2>, 3<)
Ti	Comparable and low	Comparable and low	Columns all DL
V	Comparable and low	Comparable and low	All DL
Zn	Exxon tends to be higher (V)	Shale higher, alluvium comparable	Comparable

[1] DL = Detection level.
[2] V = Some variability.

and shale media than from the Alliance waste. Values were roughly equivalent for the Exxon waste. However, alluvium leachate was very low in calcium. Similar observations pertain to the sulfate data. Leaching of the waste clearly mobilized Cl, B (Exxon), Li, K, and Sr in general. Other species depended upon the medium of comparison. The medium generally yielded greater magnesium concentrations; manganese was increased for certain media. Most of the heavy metals were comparable in the leachates from waste and disposal media. The exception was the interburden, which was obviously undergoing the typical pyrite oxidation process as evidenced by the low pH, high sulfate, and high iron concentrations. The acid in turn mobilized the heavy metals. The interburden column was a simulation of classic acid mine drainage phenomena.

The pH behavior in the field cells is of considerable interest. The Exxon PFBC cells consistently yielded much lower pH values essentially from the beginning of sample collection. Only a few early leachate values had the expected high pH. For most of the Alliance field cells, early pH values were high as expected but these soon decreased as in the Exxon cells. Thus the waste cells in the later drainage had effluent pH values very similar to the soil columns. When the soil and waste bulk chemical compositions are compared, it is not surprising that the leachate compositions were similar when pH was similar. Except for the interburden, it is doubtful that appreciable base neutralizing capacity is leached from the upper soil layer in the field cells.

E.9.2 Lower Sampling Point (Attenuation/Mobilization) Results

The attenuation or mobilization of contaminants in the field cells was evaluated by assessing the concentration at the lower sample point of the field cells and a derived parameter, fractional attenuation (A_F), which is defined as follows for each species:

$$A_F = \frac{C_U - C_L}{C_U}$$

where C_U = concentration of the species in leachate from the upper sampling point

C_L = concentration in leachate from the lower sampling point.

This parameter is a complementary parameter for laboratory fractional attenuation (A_L), which is defined in the text and Appendix D. The C_U and C_L values are from leachates collected simultaneously. It is recognized that these leachates are not "equivalent" because of lag time in the migration of leachate from the upper to the lower point, as discussed below.

E.9.2.1 Time Series Behavior of the Exxon PFBC Field Cells

The same type of time series plots used for the upper sampling points in the preceding section were used to assess concentration trends for the lower sampling point. Significant differences between the upper sampling point concentrations and those at the lower sampling point are an indication of attenuation of dissolved species by the disposal medium or mobilization of dissolved species from the medium by the waste leachate.

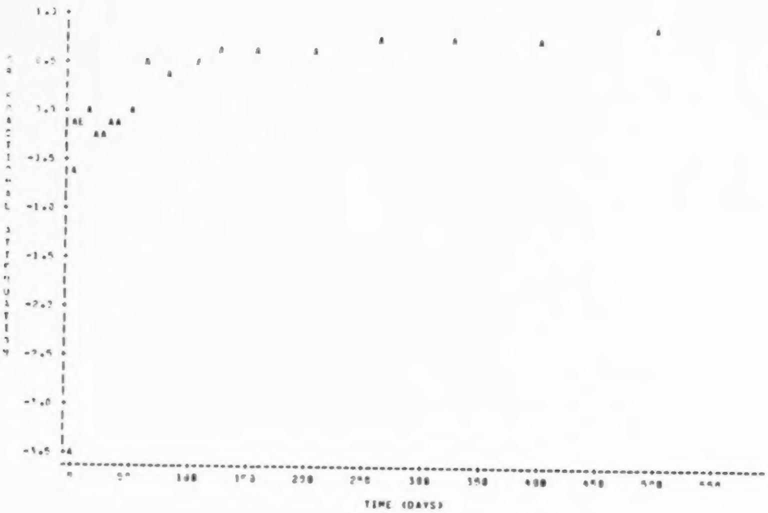
In general, the extremely high initial effluent concentrations seen for the upper sampling point of the Exxon PFBC field cells were not duplicated at the lower sampling point. Several constituents did show observable trends in the early elution volumes, but they were not typically of extreme magnitude. Table E-40 summarizes these behaviors for the Exxon PFBC field cells. A consistent pattern is not shown across all disposal media for any species. In some cases, the pH of the leachate entering the disposal medium appeared to be related to concentration of the species eluting at the lower sampling point. Some species, such as fluoride in Cell 4 and manganese in Cell 6, have much higher concentrations at the lower sample point than the leachate entering the medium from the upper sample point.

Plots of A_F for the Exxon PFBC field cells yielded a variety of behaviors. Decreasing, increasing, and oscillating values were obtained with time, and sign reversals of A_F were common. Figures E-23 to E-27 illustrate the various patterns observed.

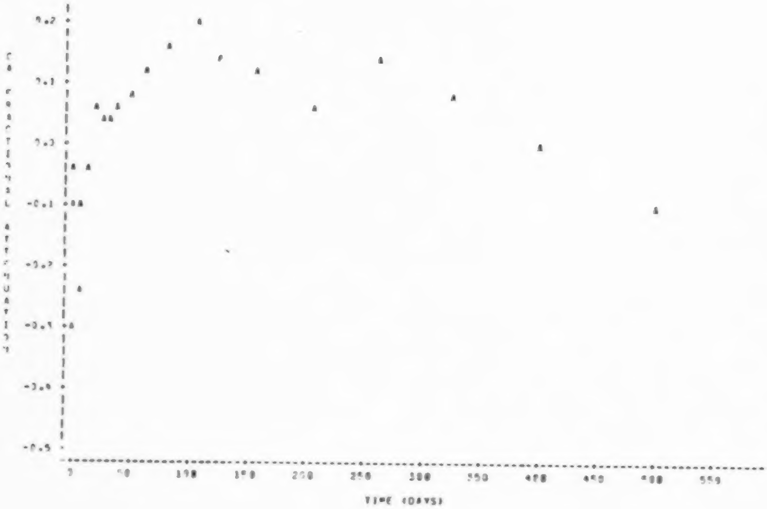
TABLE E-40. CONCENTRATION TRENDS FOR THE LOWER SAMPLE POINT OF THE EXXON PFBC FIELD CELLS (EARLY ELUTION PERIOD)

Element/ Species	Cell 1 Shale	Cell 2 Shale	Cell 3 Glacial Till	Cell 4 Limestone	Cell 5 Alluvium	Cell 6 Sandstone
Al	N	N	N	N	N	N
B	N	N	N	N	N	N
Ba	N	N	N	N	N	N
Ca	N	N	N	N	N	N
Cd	DL	DL	DL	DL	DL	DL
Cl	N	N	N	N	N	N
Co	N	N	N	N	N	D
Cr	N	N	N	N	N	N
Cu	M	M	N	N	N	M
F	N	N	N	N	N	N
Fe	N	N	N	N	N	M
Mg	N	N	I	M	I	M
Mn	M	M	M	M	I	D
Mo	N	M	N	N	N	N
Na	M	D	N	D	I	D
Ni	N	N	N	N	N	D
pH	N	N	N	N	N	N
Si	N	N	N	N	N	N
SO_4	N	N	I	D	I	M
Sp. Cond.	N	N	N	D	I	N
Sr	N	N	N	N	N	N
TDS	N	N	N	D	I	D
Ti	N	N	N	N	N	N
V	N	N	N	N	N	N
Zn	N	N	N	N	N	N

I = Increase with time.
M = Moderate decrease (from 2 to 4 times the initial values)
D = Large decrease (from 5 to 10 times the initial values)
N = No appreciable change.
DL = Detection limit.

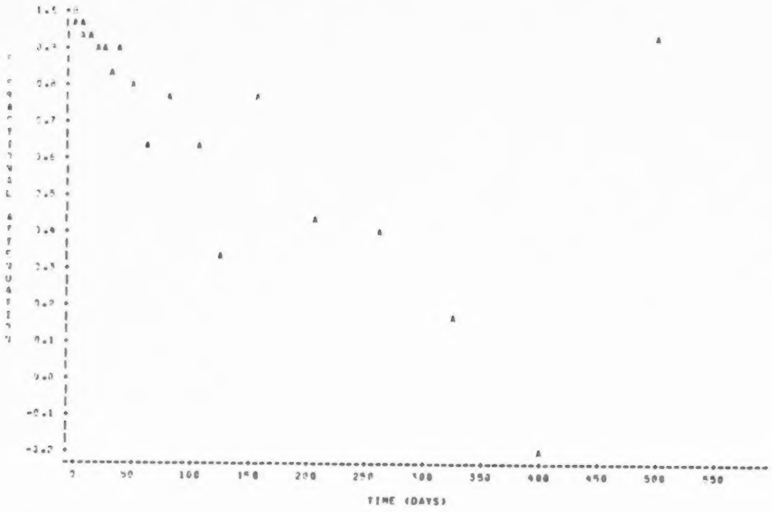


a. Fractional Attenuation of Strontium in Field Cell 3 (PFBC Waste and Shale)

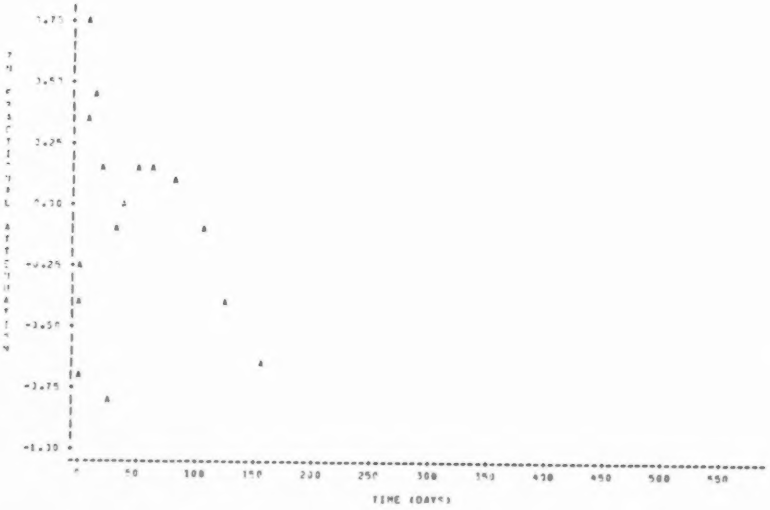


b. Fractional Attenuation of Calcium in Field Cell 6 (PFBC Waste and Sandstone)

Figure E-23. Examples of Increasing Positive Fractional Attenuation Values for Exxon PFBC Field Cells.

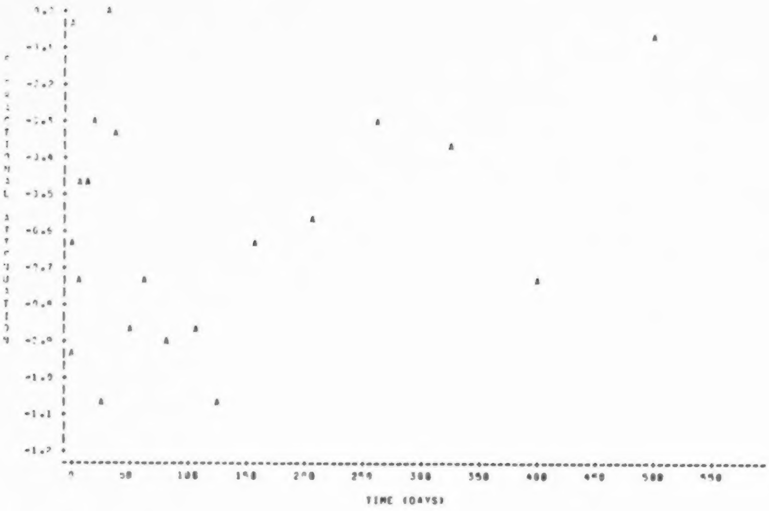


a. Fractional Attenuation of Boron in Field Cell 1 (PFBC Waste and Shale)

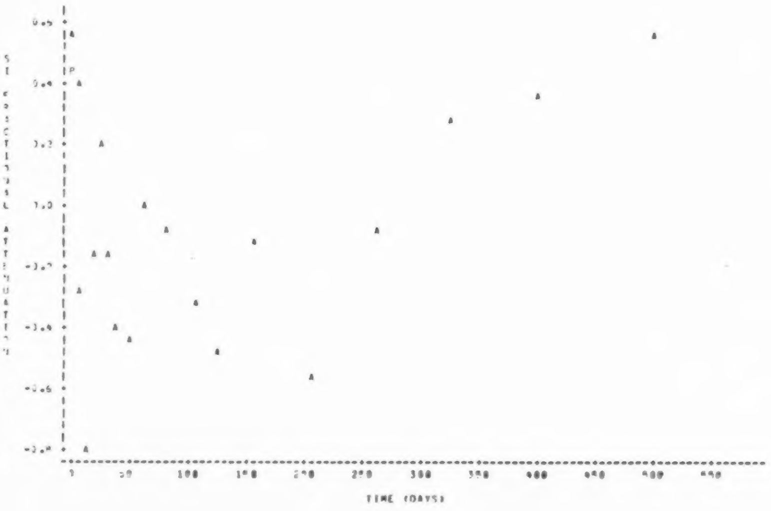


b. Fractional Attenuation of Zinc in Field Cell 1 (PFBC Waste and Shale)

Figure E-24. Examples of Decreasing (Mostly Positive) Fractional Attenuation Values for Exxon PFBC Field Cells.

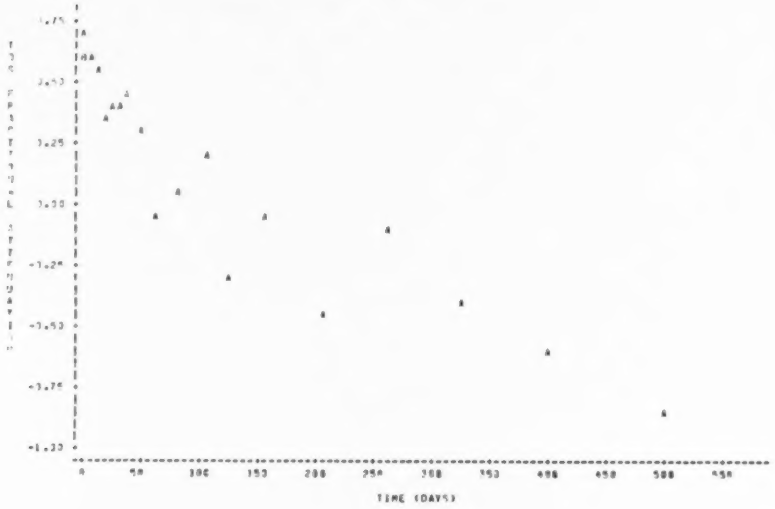


a. Fractional Attenuation of Fluoride in Field Cell 6 (PFBC Waste and Sandstone)

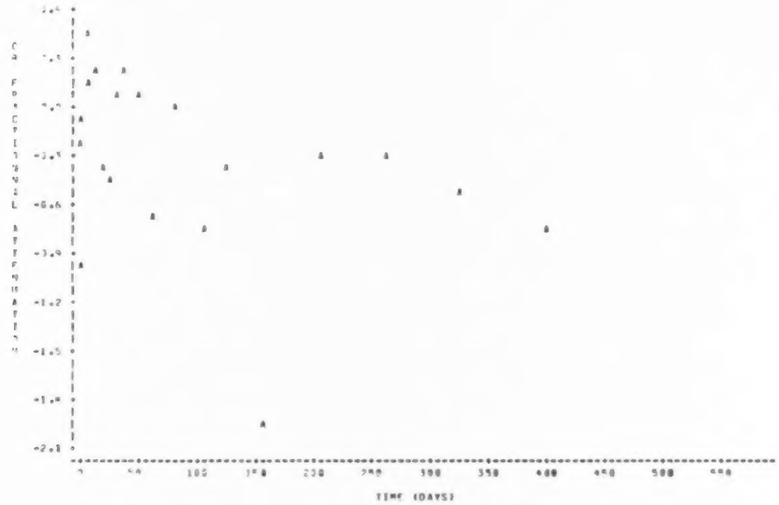


b. Fractional Attenuation of Silicon in Field Cell 4 (PFBC Waste and Limestone)

Figure E-25. Examples of Oscillating (and Erratic) Fractional Attenuation Values for Exxon PFBC Field Cells.

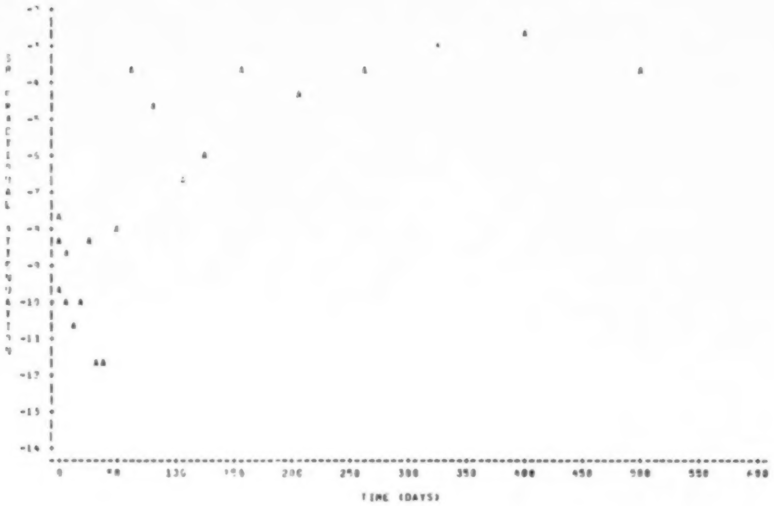


a. Fractional Attenuation of Total Dissolved Solids in Field Cell 1 (PFBC Waste and Shale)

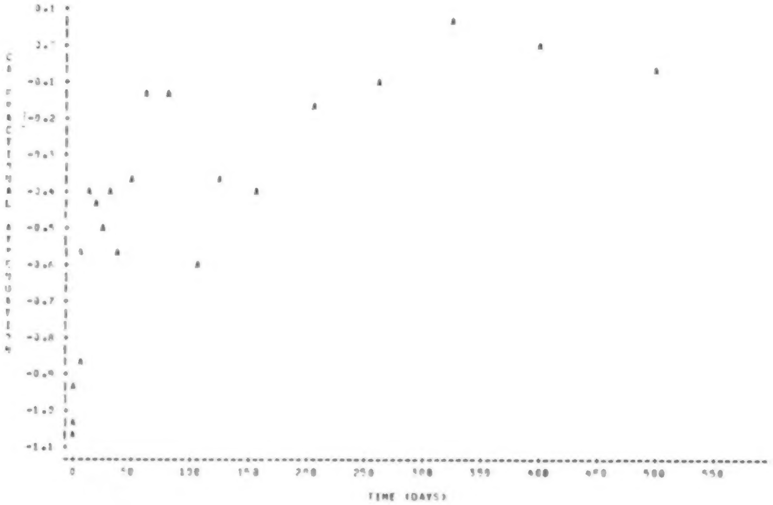


b. Fractional Attenuation of Chromium in Field Cell 1 (PFBC Waste and Shale)

Figure E-26. Examples of Declining, Negative Fractional Attenuation Values for Exxon Field Cells.



a. Fractional Attenuation of Strontium in Field Cell 4 (PFBC Waste and Limestone)



b. Fractional Attenuation of Calcium in Field Cell 1 (PFBC Waste and Shale)

Figure E-27. Examples of Increasing Negative Fractional Attenuation for Exxon PFBC Field Cells.

Figure E-23 presents two examples where a fairly steady increase for A_F was seen. Both examples had initially negative attenuation which changed to positive values with time. Over the long term, calcium attenuation reversed again.

Figure E-24 presents cases where A_F declined steadily. For zinc the decline was rapid and resulted in negative values. Very early zinc fractional attenuation values were also negative. Figure E-25 presents two examples of oscillating A_F values (increasing-decreasing) which also show considerable scatter. Figure E-26 illustrates behavior similar to Figure E-24 but emphasizing the declining A_F values after becoming negative. Figure E-27 provides examples of A_F that remained negative but increased with time.

Many plots of A_F for other species and other cells were less defined as to characteristic patterns. Most generally there was an absence of a well-defined trend. An alternate analytical approach was therefore attempted.

Of more realistic concern is the time-averaged behavior of the lower sampling point concentration, since this represents the potential environmental impact. Tables E-41 to E-46 contain summary statistics of the lower sampling point behavior for each species for each Exxon PFBC waste field cell considering only samples taken after 60 days of operation. Comparison of the mean values obtained for the lower sampling point with similar values for the upper sampling point provides an estimate of net attenuation/mobilization behavior for the field cells. Table E-47 contains these estimates in terms of fractional attenuation (A_F) of the means. Based on this approach, the following observations can be made regarding attenuation/mobilization in the Exxon field cells.

Since Cells 1 and 2 are replicates for the shale disposal medium, the first level of comparison is reproducibility of the greater-than-60-day net A_F values. Examination of Cell 1 and 2 values from Table E-47 shows good agreement of A_F values for Al, B, Cu, Mn, Mo, Sr, and perhaps V.

TABLE E-41. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 1 (EXXON PFBC WASTE AND SHALE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	1.6	1.5	0.09	2.7	2.6	0.79
B	15	3.0	2.1	0.11	10	9.9	2.4
Ba	15	0.19	0.11	0	0.75	0.75	0.23
Be	8	0	0	0	0.01	0.01	0.002
Ca	15	550	550	510	520	81	24
Cd	15	0.01	0.02	0	0.04	0.04	0.011
Cl	9	20	14	12	47	35	12
Co	15	0.03	0.01	0	0.08	0.08	0.028
Cr	15	0.04	0.02	0	0.12	0.12	0.043
Cu	15	0.02	0	0	0.11	0.11	0.034
F	15	0.22	0.21	0.16	0.34	0.18	0.049
Fe	15	0.04	0.03	0	0.17	0.17	0.043
K	15	290	290	180	530	350	87
Li	12	0.09	0.08	0	0.19	0.19	0.075
Mg	15	200	200	0.05	290	290	71
Mn	15	0.05	0.02	0	0.3	0.3	0.093
Mo	15	0.05	0.02	0	0.34	0.34	0.087
Na	15	190	180	84	270	190	54
Ni	15	0.04	0.01	0.01	0.14	0.13	0.046
pH[2]	15	7.4	7.3	7.0	7.9	0.87	0.29
Si	15	15	11	4.9	45	40	10
SO_4	15	2750	2720	2230	3410	1180	350
Sp.Cond.[3]	15	4490	4350	3790	6100	2310	650
Sr	15	1.5	1.4	1	2.26	1.3	0.31
TDS	15	4810	4520	3810	6240	2430	650
Ti	15	0.11	0.01	0	0.73	0.73	0.20
TIC	3	54	50	48	64	16	8.7
TOC	5	8	7.8	5	12	7	3.1
V	15	0.19	0.05	0	0.86	0.86	0.28
Zn	15	0.2	0.09	0.01	0.92	0.91	0.25

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[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-42. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 2 (EXXON PFBC WASTE AND SHALE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	1.7	1.8	0.14	2.6	2.5	0.81
B	15	3.5	3.4	0.45	8.8	8.4	2.1
Ba	15	0.23	0.11	0	0.86	0.86	0.27
Be	8	0	0	0	0	0	0.001
Ca	15	540	530	440	650	210	61
Cd	15	0.01	0.02	0	0.03	0.03	0.009
Cl	9	29	11	7.1	160	150	50
Co	15	0.03	0.01	0	0.07	0.07	0.025
Cr	15	0.04	0.03	0	0.14	0.14	0.042
Cu	15	0.02	0	0	0.1	0.1	0.031
F	15	0.2	0.2	0.07	0.33	0.26	0.059
Fe	15	0.07	0.06	0	0.21	0.21	0.064
K	15	330	320	160	610	450	140
Li	12	0.18	0.19	0.02	0.34	0.31	0.1
Mg	15	182	190	0.03	250	250	60
Mn	15	0.05	0.01	0	0.26	0.26	0.082
Mo	15	0.05	0.02	0	0.4	0.4	0.1
Na	15	110	100	54	210	160	42
Ni	15	0.04	0.02	0.01	0.1	0.09	0.039
pH[2]	15	7.4	7.4	7.1	7.7	0.67	0.20
Si	15	14	10	4.7	47	43	11
SO_4	15	2480	2260	1900	3350	1450	500
Sp.Cond.[3]	15	4260	3750	3100	6000	2900	990
Sr	15	1.4	1.3	1.1	2.23	1.1	0.31
TDS	15	4420	4100	3520	6330	2810	920
Ti	15	0.1	0.01	0	0.44	0.44	0.15
TIC	2	59	59	49	68	19	13
TOC	5	11	12	6.4	15	8.6	3.5
V	15	0.19	0.07	0	0.87	0.87	0.29
Zn	15	0.21	0.11	0.01	1.1	1	0.28

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[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-43. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 3 (EXXON PFBC WASTE AND GLACIAL TILL)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	16	1.7	1.4	0.07	3.3	3.2	0.97
B	16	3.3	2.9	0.79	6.3	5.5	1.9
Ba	16	0.28	0.21	0.01	0.85	0.84	0.29
Be	9	0	0	0	0	0	0
Ca	16	500	500	370	660	290	110
Cd	16	0.01	0.02	0	0.02	0.02	0.01
Cl	10	17	12	10	36	26	9.7
Co	16	0.02	0.01	0	0.07	0.07	0.02
Cr	16	0.04	0.04	0	0.15	0.15	0.04
Cu	16	0.02	0.01	0	0.08	0.08	0.03
F	16	0.48	0.39	0.34	1.8	1.5	0.35
Fe	16	0.04	0.03	0	0.13	0.13	0.04
K	16	54	48	11	160	150	39
Li	13	0.26	0.20	0.06	0.46	0.40	0.14
Mg	16	190	160	0.04	290	290	83
Mn	16	0.06	0.02	0	0.3	0.29	0.09
Mo	16	0.06	0.02	0	0.48	0.48	0.12
Na	16	160	95	62	4170	350	130
Ni	15	0.04	0.03	0.01	0.12	0.11	0.04
pH[2]	16	7.4	7.4	7.0	7.7	0.68	0.19
Si	16	22	20	13	49	36	11
SO_4	16	2050	1810	1130	3100	1970	790
Sp.Cond.[3]	16	3270	3050	2280	4500	2220	910
Sr	16	0.40	0.30	0.17	0.83	0.66	0.21
TDS	16	3660	3470	2130	5320	3190	1270
Ti	16	0.12	0.02	0	0.71	0.71	0.22
TIC	3	59	63	52	63	11	6.4
TOC	5	19	15	9.3	34	25	9.7
V	16	0.23	0.1	0	1	1	0.33
Zn	16	0.22	0.1	0.01	1.23	1.2	0.33

[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] Units are micromhos/cm.

TABLE E-44. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 4 (EXXON PFBC WASTE AND LIMESTONE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	1.5	1.5	0.08	2.5	2.4	0.78
B	15	3.9	3.3	0.88	7.7	6.8	2.1
Ba	15	0.22	0.21	0	0.85	0.85	0.25
Be	8	0	0	0	0.01	0.01	0
Ca	15	480	470	420	580	160	46
Cd	15	0.02	0.02	0	0.04	0.04	0.01
Cl	9	7.1	4.3	3.0	26	23	7.3
Co	15	0.03	0.01	0	0.07	0.07	0.03
Cr	15	0.05	0.02	0	0.23	0.23	0.07
Cu	15	0.02	0	0	0.12	0.12	0.04
F	15	1.2	1.1	0.88	1.8	0.94	0.24
Fe	15	0.08	0.02	0	0.79	0.79	0.2
K	15	270	190	140	630	490	150
Li	12	0.62	0.25	0.11	1.8	1.7	0.62
Mg	15	140	130	0.11	230	230	57
Mn	15	0.17	0.19	0	0.45	0.44	0.14
Mo	15	0.36	0.24	0	1.4	1.4	0.4
Na	15	190	180	32	690	660	200
Ni	15	0.13	0.1	0.01	0.32	0.31	0.08
pH[2]	15	7.6	7.7	7.1	7.9	0.80	0.26
Si	15	17	13	6	49	43	12
SO_4	15	2580	2090	1230	4620	330	1290
Sp.Cond.[3]	15	4520	3500	2450	7800	5350	2070
Sr	15	7.5	7.5	6.3	8.9	2.6	0.86
TDS	15	4770	3780	2310	8650	6340	2300
Ti	15	0.16	0.01	0	0.77	0.77	0.26
TIC	2	58	58	46	69	23	16
TOC	5	7.8	8.6	5	11	6	2.4
V	15	0.20	0.09	0	0.85	0.84	0.26
Zn	15	0.32	0.19	0.01	1.4	1.4	0.38

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-45. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 5 (EXXON PFBC WASTE AND ALLUVIUM)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	1.5	1.6	0.13	2.8	2.6	0.83
B	15	3	2.3	0.46	7.3	6.8	2.0
Ba	15	0.22	0.10	0	1.1	1.1	0.3
Be	9	0	0	0	0	0	0
Ca	15	340	360	200	480	280	96
Cd	15	0.01	0.02	0	0.02	0.02	0.01
Cl	9	14	9.4	6.4	39	33	11
Co	15	0.03	0.01	0	0.07	0.07	0.03
Cr	15	0.05	0.02	0	0.24	0.24	0.06
Cu	15	0.04	0.02	0	0.18	0.18	0.05
F	15	0.23	0.22	0.16	0.45	0.29	0.08
Fe	15	0.05	0.04	0	0.18	0.17	0.05
K	15	230	250	21	400	380	140
Li	12	0.11	0.02	0	0.95	0.95	0.27
Mg	15	72	28	6.8	150	140	59
Mn	15	4.6	2.0	0.01	12	12	4.5
Mo	15	0.08	0.04	0	0.46	0.46	0.12
Na	15	190	120	30	720	690	230
Ni	15	0.13	0.10	0.01	0.25	0.24	0.09
pH[2]	15	5.6	5.5	5.2	6.2	0.98	0.34
Si	15	15	12	8.8	35	26	7.7
SO_4	15	2150	1850	950	3900	2950	1170
Sp. Cond.[3]	15	3700	3000	2100	6000	3900	1640
Sr	15	0.80	0.71	0.39	1.5	1.1	0.34
TDS	15	3610	3030	1640	6110	4470	1770
Ti	15	0.15	0.06	0	0.86	0.86	0.26
TIC	2	1	1	1	1	0	0
TOC	5	5	5	3.1	7.6	4.5	1.9
V	15	0.17	0.06	0	0.62	0.62	0.22
Zn	15	0.31	0.14	0.01	1.7	1.6	0.47

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[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-46. SUMMARY STATISTICS FOR LOWER SAMPLEG POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 6 (EXXON PFBC WASTE AND SANDSTONE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	2.8	3.0	0.17	4.8	4.6	1.4
B	15	3.8	3.3	0	10	10	2.7
Ba	15	0.23	0.16	0	0.89	0.89	0.27
Be	8	0	0	0	0.01	0.01	0
Ca	15	500	510	430	600	170	53
Cd	15	0.01	0.02	0	0.04	0.04	0.01
Cl	9	16	13	12	25	13	5.6
Co	15	0.03	0.01	0	0.08	0.08	0.03
Cr	15	0.06	0.03	0	0.23	0.23	0.07
Cu	15	0.04	0	0	0.15	0.15	0.05
F	15	0.34	0.32	0.17	0.69	0.52	0.12
Fe	15	0.05	0.05	0	0.12	0.12	0.04
K	15	390	360	250	610	360	110
Li	12	0.85	0.62	0.42	1.6	1.2	0.45
Mg	15	310	330	1.3	400	400	98
Mn	15	3.0	0.19	0	11	11	4.1
Mo	15	0.08	0.05	0	0.49	0.49	0.13
Na	15	110	76	59	270	210	61
Ni	15	0.09	0.09	0.01	0.22	0.21	0.07
pH[2]	15	7.28	7.29	7.01	7.57	0.56	0.17
Si	15	13	10	4	41	37	9.4
SO_4	15	3150	2890	2440	4300	1860	660
Sp.Cond.[3]	15	4850	4300	3600	6750	3150	1090
Sr	15	1.7	1.6	1.2	2.4	1.2	0.34
TDS	15	5290	4760	4210	7080	2870	1110
Ti	15	0.18	0.03	0	0.8	0.8	0.26
TIC	2	56	56	54	58	4	2.8
TOC	5	4	3.8	2.1	5.3	3.2	1.3
V	15	0.31	0.18	0	1.3	1.3	0.41
Zn	15	0.36	0.13	0.01	1.8	1.8	0.53

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-47. AVERAGE FRACTIONAL ATTENUATION (AFTER 60 DAYS) FOR THE EXXON PFBC FIELD CELLS

Element/ Species	Cell 1 Shale	Cell 2 Shale	Cell 3 Glacial Till	Cell 4 Limestone	Cell 5 Alluvium	Cell 6 Sandstone
Al	-0.87	-0.68	-1.6	-1.5	-1.1	-1.8
B	0.31	0.34	0.32	0.084	0.11	0.052
Ba	0.24	-0.13	-0.044	0.21	0.11	0.13
Be	-	-	-	1	-	-
Ca	-0.078	0.12	0.019	0.074	0.14	0.045
Cr	0.063	0.35	-0.054	-0.67	-0.51	-0.93
Cu	0.26	0.16	0.3	0.0035	-1	-2.1
Fe	0.69	0.14	0.48	-0.84	-0.13	0.49
K	0.18	0.3	0.83	-0.036	0.58	-0.57
Li	0.837	0.58	0.56	-0.54	0.91	-0.42
Mg	-2.7	-0.77	-3.2	-4.4	-2.2	-2.8
Mn	0.96	0.99	0.94	0.32	-13	-9.9
Mo	0.71	0.60	0.82	-1.2	0.56	0.53
Na	-0.68	0.39	-0.83	-1.5	-0.13	-0.63
Si	0.14	0.51	0.24	0.21	0.59	0.30
SO_4	-0.36	0.098	-0.064	-0.56	-0.048	-0.69
Sr	-0.23	-0.15	0.67	-3.8	0.38	-0.38
Ti	-0.4	-0.058	-0.23	-0.29	-0.14	-0.2
TIC	-0.42	-0.86	-3.4	-0.15	1	-0.22
V	-0.31	-0.11	-0.51	-1	-0.68	-0.67
Zn	-0.6	0.18	-0.53	-0.99	-1.3	-0.59

Several other species were in approximate agreement; i.e., they had the same sign but wider variation in the magnitude of the respective A_F values. These species were Cr, Fe, Li, Mg, Si, and Ti.

For six species, the replicate column A_F values did not agree in sign. The A_F values for Cu, Ni, Na, SO_4, and Zn were negative for Cell 1 and positive for Cell 2. The barium A_F value was positive for Cell 1 and negative for Cell 2. The maximium absolute magnitude of the A_F value is not small in many of these cases.

Comparison of species attenuation behavior for all six Exxon PFBC field cells yields only six species with consistent A_F sign. Boron and silicon were consistently attenuated for all six cells. Al, Mg, Ti, and V were consistently mobilized in all six cells.

With the exception of one A_F value (and in all 4 cases, the odd value was one of the replicates) calcium was consistently attenuated and Ni, Na, SO_4, and Zn were consistently mobilized. Similarly, except for the limestone medium, molybdenum was attenuated in the other five columns, while chromium was mobilized in all but the shale cells.

By arbitrarily selecting $A_F \geq 0.3$ as a means of assessment (and requiring that both shale values meet the criterion for Cells 1 and 2) for strength of long term attenuation, a comparison of the 5 media can be made. Glacial till had six A_F values greater than or equal to 0.3, alluvium had five, shale and sandstone each had three and the limestone medium had only one.

E.9.2.2 Time Series Behavior of the Alliance AFBC Field Cells

Table E-48 contains a summary of the early elution behavior of the Alliance AFBC field cells at the lower sampling point. It is immediately apparent that Cell 13, which contains interburden, is atypical and that the potential for control of the "acid mine drainage" phenomenon by alkaline waste leachate is not manifested. For most species, much higher values were

TABLE E-48. CONCENTRATION TRENDS FOR THE LOWER SAMPLE POINT OF THE ALLIANCE AFBC FIELD CELLS (EARLY ELUTION PERIOD)

Element/ Species	Cell 13 Interburden	Cell 14 Alluvium	Cell 15 Alluvium	Cell 16 Limestone	Cell 17 Shale
Al	D	–	N	N	N
B	N	–	N	M	N
Ba	N	–	N	N	N
Ca	N	I	I	M	N
Cd	D	DL	DL	DL	DL
Cl	D	N	I	D	M
Co	N	DL	DL	DL	DL
Cr	N	N	N	D	N
Cu	N	N	N	N	N
F	N	N	N	N	N
Fe	D	N	N	N	N
K	N	–	N	N	N
Li	N	–	D	N	N
Mg	D	–	D	D	N
Mn	N	–	N	I	D
Mo	N	–	N	N	N
Na	–	–	N	N	I
Ni	N	N	N	N	N
pH	N	N	N	N	N
Si	I	N	N	N	N
SO_4	D	–	N	N	N
Sp.Cond.	D	I	N	N	N
Sr	N	N	N	N	N
TDS	D	–	I	N	N
Ti	N	–	N	N	N
V	N	N	N	N	N
Zn	N	N	N	N	N

I = Increase with time.
M = Moderate decrease (from 2 to 4 times the initial values).
D = Large decrease (from 5 to 10 times the initial values).
N = No appreciable change.
DL = Detection limit.

obtained for the lower sampling point eluant than for the waste leachate entering the interburden layer from the upper sample point. Both high acidity and higher matrix concentrations in the interburden were responsible. A concentration depending on time with initially high values is indicated for many species. The very high sulfate in Cell 13 was most likely the result of pyrite oxidation in the soil.

Compared to the Exxon PFBC cells, more species in the other four Alliance field cells show an initial time-of-elution dependency. Several of these are inverse relationships and are likely attributable to the high pH of the waste leachates entering the soils. Such pH behavior was not seen for the PFBC cells.

The time shift between changes in the upper sampling point concentration and the lower sampling point concentration is apparent in many more cases with the Alliance field cells because of the pH changes. Although mediation by the soil matrix may have been involved, a strong indication of appreciable lag (20 days or more) was found in these data. Tables E-49 to E-53 present the summary statistics for the Alliance field cell lower sampling point concentrations. These values are combined with the corresponding data for the upper sampling point to yield net fractional attenuation values based on mean concentrations after 60 days (Table E-54).

Selected comparisons can be made with the plots of A_F versus time shown in Figures E-28 to E-32 for the Alliance AFBC field cells. The following observations can be made from Table E-54 and Figures E-28 to E-32.

Since Cells 14 and 15 are replicates for the alluvium disposal medium, the first level of comparison is reproducibility of the greather-than-60-day net A_F values. Examination of Cell 14 and 15 values from Table E-54 shows good agreement for all A_F values except calcium and iron, where values of opposite sign were obtained (i.e., negative values for Cell 14 and positive for Cell 15 in both cases). In a few cases (i.e., magnesium, manganese, and nickel) the absolute magnitude of the replicates was quite different. However, the actual concentrations were quite low for these species

TABLE E-49. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 13 (ALLIANCE AFBC WASTE AND INTERBURDEN)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	12	520	500	160	1100	940	350
B	12	38	2.6	0.34	380	380	110
Ba	12	0.2	0.1	0	0.8	0.8	0.28
Be	12	0.3	0.2	0	1.1	1.1	0.35
Ca	12	520	520	450	630	180	56
Cd	12	0.3	0.1	0.01	1	1	0.34
Cl	12	38	28	8.6	110	98	33
Co	12	4.0	3.5	0.74	11	10	3.4
Cr	12	0.3	0.2	0	1.2	1.2	0.4
Cu	12	8	5	0	20	20	7
F	12	3.5	2.8	2.5	7.6	5.1	1.5
Fe	12	1050	1080	360	2080	1720	610
K	12	110	98	24	210	190	54
Li	12	3.6	3.4	1.4	5.8	4.4	1.8
Mg	12	310	220	100	830	730	240
Mn	12	8.8	6.9	1.9	19	17	6.9
Mo	12	0.2	0.2	0	0.5	0.5	0.16
Na	12	46	38	18	97	79	25
Ni	12	9.1	7.7	0.32	24	24	7.5
pH[2]	12	2.1	2.1	2.0	2.4	0.5	0.13
Si	12	98	87	67	160	93	31
SO_4	12	9420	8740	3750	23300	19550	5880
Sp. Cond.[3]	12	7590	7650	4800	11000	6200	2090
Sr	12	7.5	6	3.5	21	18	4.7
TDS	12	13160	12515	5380	27400	22020	7320
Ti	12	0	0	0	0	0	0.01
TIC	2	1	1	1	1	0	0
V	12	0.3	0.3	0.01	1	1	0.33
Zn	12	17	8.6	2.9	43	40	14

[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] Units are micromhos/cm.

TABLE E-50. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 14 (ALLIANCE AFBC WASTE AND ALLUVIUM)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	12	4.0	0.77	0.13	38	38	11
B	12	8.3	0.19	0	92	92	26
Ba	12	0.47	0.43	0	1.1	1.1	0.38
Be	12	0	0	0	0	0	0.001
Ca	12	240	220	150	320	170	57
Cd	12	0.01	0.01	0	0.02	0.02	0.008
Cl	12	320	220	120	850	730	230
Co	12	0.01	0.01	0	0.01	0.01	0.006
Cr	12	0.02	0	0	0.13	0.13	0.006
Cu	12	0.01	0.01	0	0.03	0.03	0.013
F	12	0.15	0.1	0.08	0.64	0.56	0.16
Fe	12	0.72	0.46	0.02	2.5	2.5	0.8
K	12	9.6	9.9	4.4	15	11	2.9
Li	12	0	0	0	0.02	0.02	0.005
Mg	12	56	51	36	110	74	20
Mn	12	0.96	0.91	0.41	1.8	1.4	0.47
Mo	12	0	0	0	0.02	0.02	0.006
Na	12	92	94	25	140	120	38
Ni	12	0.05	0.04	0.01	0.14	0.13	0.043
pH[2]	12	5.5	5.7	4.3	6.5	2.3	0.56
Si	12	9.8	9.6	7.8	12	4.2	1.3
SO_4	12	430	457	56	820	770	280
Sp. Cond.[3]	12	1780	1810	1140	2400	1260	390
Sr	12	0.85	0.8	0.35	1.6	1.3	0.38
TDS	12	1680	1650	1050	2300	1250	350
Ti	12	0.01	0.01	0	0.01	0.01	0.005
TIC	2	1	1	1	1	0	0
TOC	1	10	10	10	10	0	-
V	12	0.01	0.01	0	0.005	0.015	0.015
Zn	12	0.12	0.11	0.07	0.19	0.12	0.039

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-51. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 15 (ALLIANCE AFBC WASTE AND ALLUVIUM)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	12	2.5	0.71	0.13	23	23	6.5
B	12	9.7	0.44	0	110	110	32
Ba	12	0.59	0.45	0.25	1.7	1.5	0.44
Be	12	0	0	0	0.01	0.008	0.002
Ca	12	200	200	170	260	90	24
Cd	12	0.01	0.01	0	0.02	0.017	0.008
Cl	12	340	360	270	430	160	53
Co	12	0.01	0.01	0	0.03	0.027	0.008
Cr	12	0.01	0	0	0.12	0.12	0.034
Cu	12	0	0	0	0.02	0.015	0.004
F	12	0.12	0.09	0.05	0.48	0.43	0.12
Fe	12	0.07	0.06	0	0.22	0.22	0.062
K	12	8.9	9.0	3.5	12	8.5	2.1
Li	12	0	0	0	0	0.002	0
Mg	12	49	47	36	87	51	14
Mn	12	1.2	1.2	0.62	2.2	1.6	0.47
Mo	12	0	0	0	0.01	0.014	0.004
Na	12	53	40	32	110	78	24
Ni	12	0.05	0.04	0.01	0.12	0.11	0.033
pH[2]	12	6.3	6.3	5.7	6.7	0.99	0.31
Si	12	9.5	9.4	7.0	13	6.0	1.8
SO_4	12	220	150	71	450	380	150
Sp. Cond.[3]	12	1510	1510	1380	1650	270	97
Sr	12	0.83	0.81	0.63	0.98	0.35	0.098
TDS	12	1380	1310	1120	1660	540	180
Ti	12	0.01	0.01	0	0.01	0.01	0.004
TIC	2	1	1	1	1	0	0
TOC	1	5.7	5.7	5.7	5.7	0	–
V	12	0.02	0.01	0	0.09	0.09	0.025
Zn	12	0.11	0.1	0.05	0.29	0.24	0.06

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[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-52. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 16 (ALLIANCE AFBC WASTE AND LIMESTONE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	12	5.6	1.6	0.69	50	49	14
B	12	13	1.8	0.41	130	130	37
Ba	12	0.41	0.3	0	1.2	1.2	0.42
Be	12	0	0	0	0	0	0.001
Ca	12	390	380	240	660	420	140
Cd	12	0.01	0.02	0	0.03	0.03	0.009
Cl	12	99	88	50	210	160	42
Co	12	0.02	0.01	0	0.06	0.06	0.017
Cr	12	0.02	0	0	0.13	0.13	0.043
Cu	12	0.02	0	0	0.09	0.09	0.032
F	12	1.3	1.4	1.0	1.6	0.58	0.18
Fe	12	0.05	0.03	0	0.18	0.18	0.058
K	12	320	320	160	600	440	140
Li	12	2	2	1.5	2.7	1.2	0.34
Mg	12	140	125	100	270	170	45
Mn	12	0.18	0.13	0	0.56	0.56	0.19
Mo	12	1	1	0.67	1.3	0.63	0.21
Na	12	240	240	110	420	310	98
Ni	12	0.06	0.03	0	0.2	0.2	0.064
pH[2]	12	7.5	7.5	7.2	7.9	0.71	0.23
Si	12	20	20	14	27	13	4.1
SO_4	12	1860	1880	1200	2580	1300	470
Sp.Cond.[3]	12	3700	3790	2680	5000	2320	740
Sr	12	12	11	8.5	20	12	3.2
TDS	12	3720	3620	2560	5430	2870	950
Ti	12	0.05	0.01	0	0.22	0.22	0.067
TIC	2	55	55	48	61	13	9.2
TOC	1	41	41	41	41	0	–
V	12	0.04	0.01	0	0.2	0.2	0.067
Zn	12	0.09	0.08	0.01	0.18	0.17	0.051

[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-53. SUMMARY STATISTICS FOR LOWER SAMPLE POINT CONCENTRATIONS AFTER 60 DAYS: FIELD CELL 17 (ALLIANCE AFBC WASTE AND SHALE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	12	10	2.2	1.4	99	98	28
B	12	13	2.1	0	130	130	37
Ba	12	0.26	0.15	0	0.99	0.99	0.31
Be	12	0	0	0	0.01	0.01	0.003
Ca	12	680	660	580	870	290	85
Cd	12	0.02	0.02	0	0.06	0.06	0.016
Cl	12	140	90	40	480	440	140
Co	12	0.02	0.01	0	0.12	0.12	0.032
Cr	12	0.04	0.01	0	0.19	0.19	0.064
Cu	12	0.03	0	0	0.2	0.2	0.061
F	12	0.16	0.15	0.08	0.37	0.29	0.081
Fe	12	0.18	0.04	0	0.87	0.87	0.32
K	12	65	60	25	110	85	29
Li	12	0.04	0.02	0	0.17	0.17	0.050
Mg	12	240	230	200	460	260	71
Mn	12	0.25	0.01	0	1.1	1.1	0.43
Mo	12	0.02	0	0	0.13	0.13	0.036
Na	12	100	110	33	160	130	35
Ni	12	0.05	0.03	0	0.16	0.16	0.054
pH[2]	12	7.5	7.5	7.0	7.7	0.67	0.23
Si	12	9.9	9.2	5.9	17	11	3.6
SO_4	12	2070	2090	1710	2490	780	230
Sp.Cond.[3]	12	3610	3470	3280	4150	870	320
Sr	12	3.8	2.3	1.0	21	20	5.5
TDS	11	4000	3870	3440	4760	1320	410
Ti	12	0.05	0.01	0	0.45	0.45	0.13
TIC	2	60	60	49	71	22	16
TOC	1	18	18	18	18	0	-
V	12	0.06	0.01	0	0.42	0.42	0.12
Zn	12	0.08	0.07	0	0.16	0.16	0.043

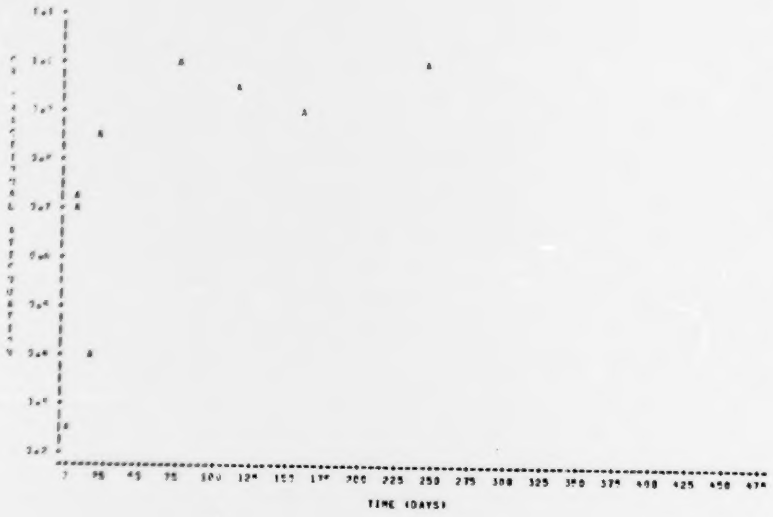
[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

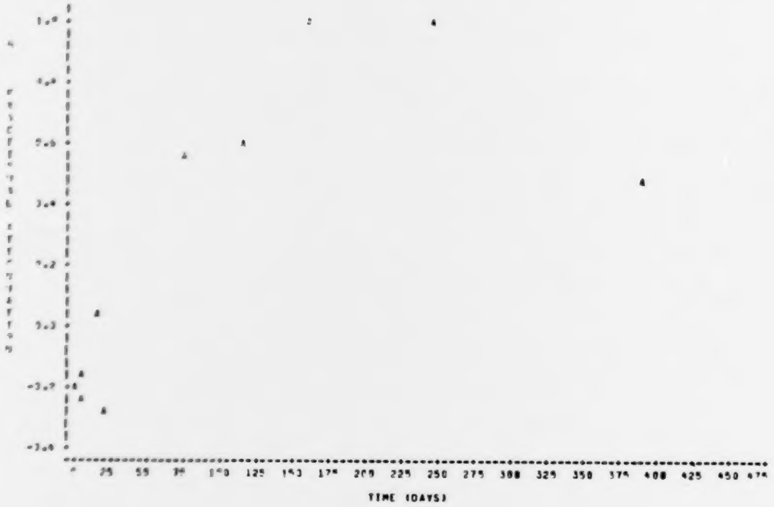
[3] Units are micromhos/cm.

TABLE E-54. AVERAGE FRACTIONAL ATTENUATION (AFTER 60 DAYS) FOR THE ALLIANCE AFBC FIELD CELLS

Element/ Species	Cell 13 Interburden	Cell 14 Alluvium	Cell 15 Alluvium	Cell 16 Limestone	Cell 17 Shale
Al	-2970	-7.4	-4.5	-17	-35
B	-5.6	-8.3	-12	-0.25	-0.18
Ba	0.33	-0.45	-0.29	-0.4	0.18
Ca	-1	-0.39	0.23	-0.19	-0.63
Cr	-28	0.81	0.62	-0.45	-0.99
Cu	-	0.36	1	-1	-1.1
Fe	-5070	-0.57	0.11	-1.7	-2.6
K	0.72	0.97	0.98	0.27	0.82
Li	-1.0	1	1	-0.13	0.97
Mg	-270	-120	-13	-400	-260
Mn	-87	-57	-350	0.36	-0.67
Mo	0.75	1	1	-0.058	0.98
Na	0.59	0.53	0.8	-1	-0.14
Ni	-1490	-0.18	-23	-2.6	-1.6
Si	-2.7	0.81	0.82	0.18	0.42
SO_4	-5.8	0.68	0.87	-0.6	-0.85
Sr	0.64	0.97	0.89	0.57	0.86
Ti	-	1	-	-21	-1.5
TIC	1	-	-	-0.38	-0.54
V	-16	0.95	0.86	-0.14	-0.79
Zn	-950	-	-	-3.6	-3.7

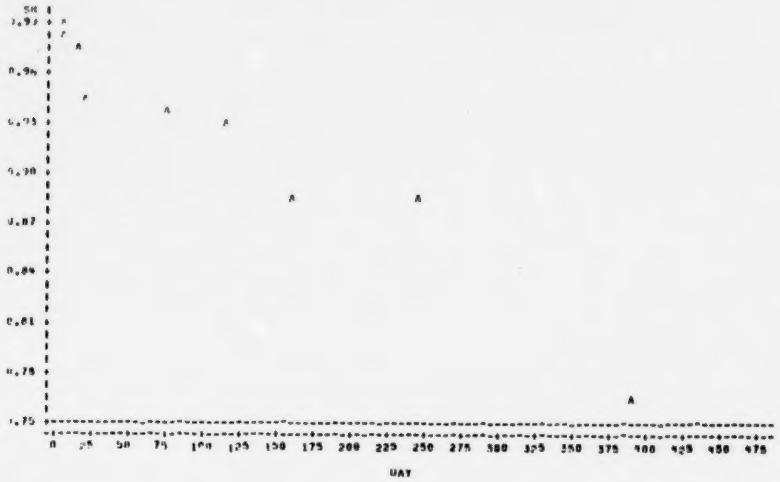


a. Fractional Attenuation of Chromium in Field Cell 15 (Alliance AFBC Waste and Alluvium)

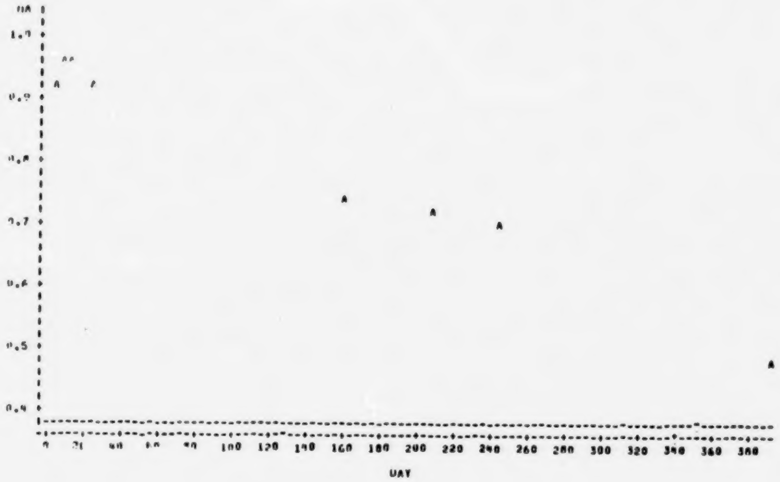


b. Fractional Attenuation of Boron in Field Cell 15 (Alliance AFBC Waste and Alluvium)

Figure E-28. Examples of Increasing Positive Fractional Attenuation Values for Alliance AFBC Field Cells.

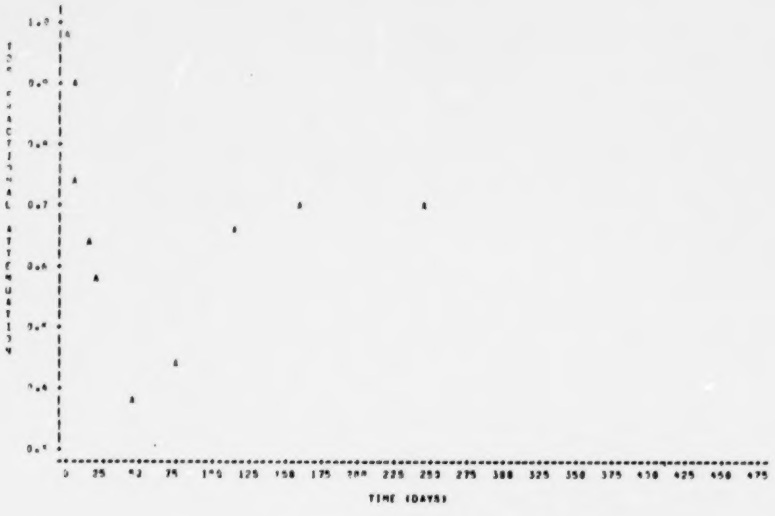


a. Fractional Attenuation of Strontium in Field Cell 15 (Alliance AFBC Waste and Alluvium)

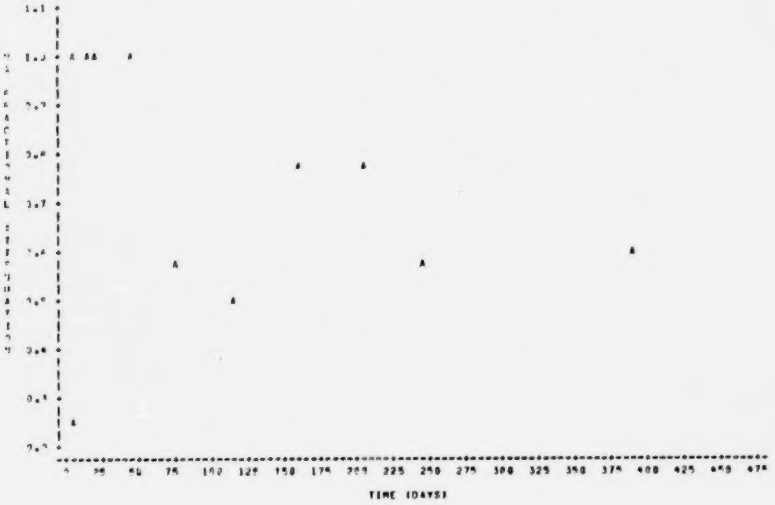


b. Fractional Attenuation of Sodium in Field Cell 15 (Alliance AFBC Waste and Alluvium)

Figure E-29. Examples of Decreasing Positive Fractional Attenuation Values for Alliance AFBC Field Cells.

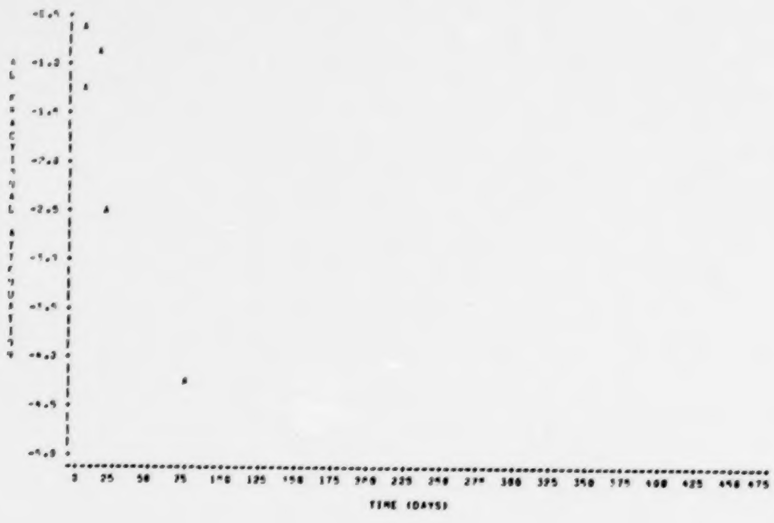


a. Fractional Attenuation of Total Dissolved Solids in Field Cell 15 (Alliance AFBC Waste and Alluvium)

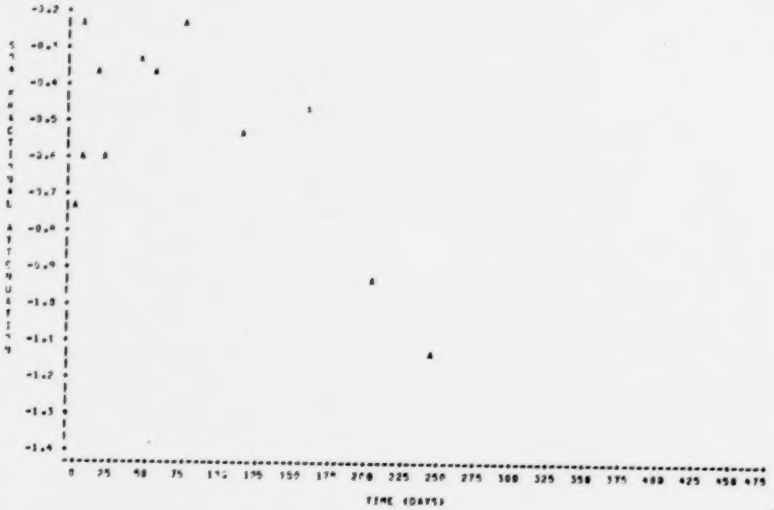


b. Fractional Attenuation of Sodium in Field Cell 13 (Alliance AFBC Waste and Interburden)

Figure E-30. Examples of Oscillating Fractional Attenuation Values for Alliance AFBC Field Cells.

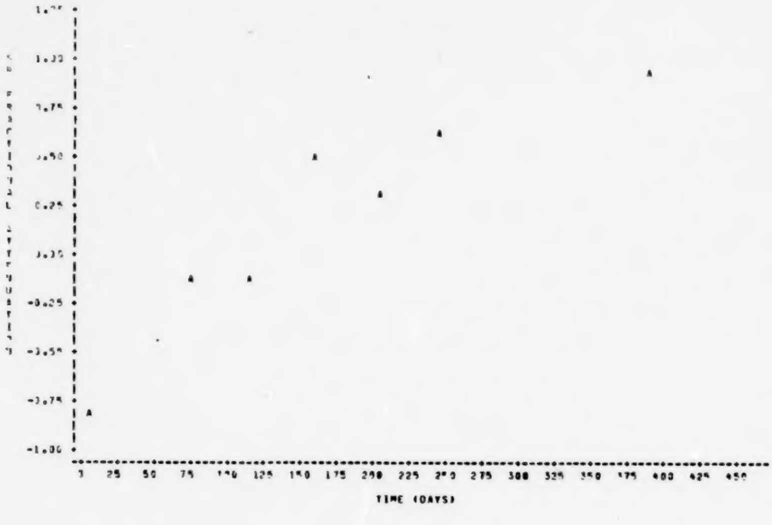


a. Fractional Attenuation of Aluminum in Field Cell 16 (Alliance AFBC Waste and Limestone)

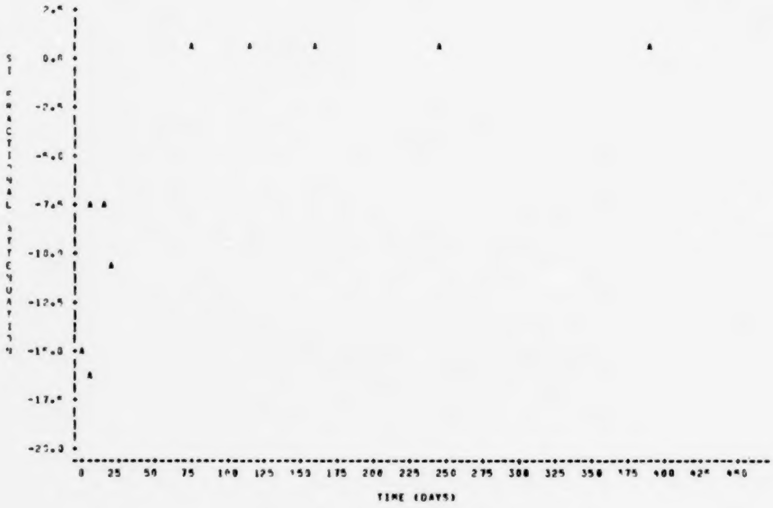


b. Fractional Attenuation of Sulfate in Field Cell 16 (Alliance AFBC Waste and Limestone)

Figure E-31. Examples of Decreasing Negative Fractional Attenuation Values for Alliance AFBC Field Cells.



a. Fractional Attenuation of Strontium in Field Cell 13 (Alliance AFBC Waste and Interburden)



b. Fractional Attenuation of Silicon in Field Cell 15 (Alliance AFBC Waste and Alluvium)

Figure E-32. Examples of Increasing (Negative to Positive) Fractional Attenuation Values for Alliance AFBC Field Cells.

and such wide variation in A_F is a consequence. In general, quite good agreement was obtained for the replicate A_F values.

Comparison of A_F values for each species across the five field cells (four media) reveals that consistent behavior was obtained for six species: Al, B, Mg, Ni, K, and Sr. The first four had negative A_F values for each of the four media. Calcium and iron also showed net mobilization in all four media except for the Cell 15 replicate for the alluvium medium. Potassium and strontium had net attenuation in all four media. A_F for zinc was not obtained for the alluvium system, but was negative for the other three media.

By arbitrarily selecting $A_F \geq 0.3$ as a means of assessment for strength of long term attenuation, a comparison of the four media can be made. The alluvium had 11 species (only one column had usable data for titanium) with moderate to high net attenuation. Much less attenuation was seen for the other three media with five species for shale, four for the interburden, and two for the limestone having $A_F \geq 0.3$.

E.9.2.3 Comparison of the Two Wastes

The field cells for the two wastes have three disposal media in common, shale, alluvium, and limestone. The shale and alluvium had duplicate cells for one of the wastes or the other. A summary of the signs only of A_F for each of the field cells (greater-than-60-day average) is contained in Table E-55. A plus sign (+) indicates net attenuation and a minus sign (-) indicates net mobilization.

When signs differ for duplicate cells with a given waste, it is difficult to make a comparison with the other waste system. For the shale medium, Ba, Ca, Ni, Na, SO_4, and Zn had opposing signs in the two duplicate cells. Of the remaining 14 species, eight (Al, Li, Mg, Mo, K, Si, Ti, and V) yielded A_F values with the same sign, and the remaining six (B, Cr, Cu, Fe, Mn, and Sr) yielded A_F values opposite in sign for the two wastes.

TABLE E-55. COMPARISON OF FRACTIONAL ATTENUATION SIGNS (INDICATING ATTENUATION OR MOBILIZATION) FOR THE EXXON PFBC AND ALLIANCE AFBC FIELD CELLS

Element/ Species	Shale			Alluvium			Limestone	
	Exxon PFBC		Alliance AFBC	Exxon PFBC	Alliance AFBC		Exxon PFBC	Alliance AFBC
	Cell 1	Cell 2	Cell 17	Cell 5	Cell 14	Cell 15	Cell 4	Cell 16
Al	−	−	−	−	−	−	−	−
B	+	+	−	+	−	−	+	−
Ba	+	−	+	+	−	−	+	−
Ca	−	+	−	+	−	+	+	−
Cr	+	+	−	−	+	+	−	−
Cu	+	+	−	−	+	+	+	−
Fe	+	+	−	−	−	+	−	−
K	+	+	+	+	+	+	−	+
Li	+	+	+	+	+	+	−	−
Mg	−	−	−	−	−	−	−	−
Mn	+	+	−	−	−	−	+	+
Mo	+	+	+	+	+	+	−	−
Na	−	+	−	−	+	+	−	−
Ni	−	+	−	−	−	−	−	−
Si	+	+	+	+	+	+	+	+
SO	−	+	−	−	+	+	−	−
Sr	−	−	+	+	+	+	−	+
Ti	−	−	−	−	+	X	−	−
V	−	−	−	−	+	+	−	−
Zn	−	+	−	−	X	X	−	−

+ = Net attenuation
− = Net mobilization
X = Attenuation not computed

For the field cells containing alluvium, only calcium and iron yielded duplicate A_F values opposite in sign for the duplicate columns. Of the remaining 17 species (A_F was not available for Zn for the Alliance waste) nine A_F values were of the same sign (Al, Li, Mg, Mn, Mo, Ni, K, Si, and Sr). For the field cells containing limestone, 14 A_F values had the same sign; only Ba, B, Ca, Cu, K, and Sr had sign reversals. No duplicate limestone columns were prepared for either waste.

Of the 19 species available for comparison among the three media (no zinc for the alluvium system) for the two wastes, only three species had A_F values with consistently positive or negative sign. These were aluminum (negative), magnesium (negative), and silicon (positive). Nickel was nearly always mobilized (except for the one shale replicate value that was positive) as were zinc and titanium. For the remainder of species, the A_F values appeared to be both waste- and medium-related.

E.9.3 Field Control Cells

Except for potassium in Cell 7 and vanadium in Cell 12, the concentrations in the field control cells (containing media only) did not decline rapidly in the early sampling period. However, to be consistent with the treatment of the waste field cell data, the summary statistics of Tables E-56 and Table E-57 were generated for the data of samples taken after 60 days of operation.

Tables E-58 to E-62 contain mean post-60-day concentrations for the Exxon PFBC waste and corresponding laboratory and field control (media only) columns for each of the individual media. Tables E-63 to E-67 contain similar data for the Alliance AFBC waste units.

Some general patterns can be discerned from these tables. For the Exxon waste cells, higher calcium concentrations resulted from the control columns (lab and field) than from the waste-containing columns when shale and sandstone were the attenuating media. These media also released high sulfate although not necessarily higher than the waste cells. Boron was

TABLE E-56. SUMMARY STATISTICS FOR FIELD CONTROL CELL CONCENTRATIONS AFTER 60 DAYS: CELL 7 (SHALE)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	2.1	1.8	0.15	4.2	4.1	1.2
B	15	1.7	1.1	0	7.2	7.2	2.0
Ba	15	0.25	0.17	0	0.93	0.93	0.28
Be	8	0	0	0	0.01	0.01	0.002
Ca	15	1000	670	580	3290	2710	830
Cd	15	0.04	0.02	0	0.24	0.23	0.064
Cl	9	1.4	1.0	1.0	3.3	2.3	0.88
Co	15	0.08	0.03	0	0.39	0.39	0.11
Cr	15	0.15	0.08	0	0.71	0.71	0.2
Cu	15	0.1	0.04	0	0.91	0.91	0.23
F	15	0.19	0.2	0.1	0.28	0.18	0.053
Fe	15	0.07	0.04	0	0.23	0.22	0.067
K	15	65	50	11	230	220	63
Li	8	0.03	0	0	0.11	0.11	0.046
Mg	15	210	210	0.03	310	310	73
Mn	15	0.08	0.03	0	0.33	0.33	0.11
Mo	15	0.09	0.05	0	0.49	0.49	0.13
Na	15	6.1	7.1	0	10	10	3.0
Ni	14	0.14	0.1	0.01	0.73	0.72	0.2
pH[2]	15	7.26	7.28	6.91	7.60	0.69	0.22
Si	15	15	9.9	5.4	42	37	12
SO_4	15	2060	2060	1890	2250	360	120
Sp. Cond.[3]	15	3170	3150	2880	3580	700	220
Sr	15	1.8	1.5	1.2	3.2	2	0.63
TDS	15	3670	3630	3260	4170	910	240
Ti	15	0.19	0.04	0	0.99	0.99	0.3
TIC	2	75	75	71	79	8	5.7
TOC	5	8.9	8.9	4.1	15	11	4.1
V	15	0.25	0.15	0	0.81	0.81	0.28
Zn	15	0.3	0.17	0.01	1.5	1.5	0.4

[1] Concentrations are in mg/L unless otherwise noted.
[2] Units are standard pH units.
[3] Units are micromhos/cm.

TABLE E-57. SUMMARY STATISTICS FOR FIELD CONTROL CELL CONCENTRATIONS AFTER 60 DAYS: CELL 12 (ALLUVIUM)[1]

Element/ Species	Number of Observations	Mean	Median	Minimum	Maximum	Range	Standard Deviation
Al	15	0.69	0.63	0.03	1.6	1.6	0.5
B	15	0.61	0.093	0.002	2.7	2.7	0.94
Ba	15	0.32	0.26	0.007	0.96	0.95	0.3
Be	8	0.001	0.001	0	0	0	0
Ca	15	79	30	9.3	590	580	150
Cd	15	0.033	0.012	0.002	0.22	0.22	0.06
Cl	7	1	1	1	1	0	0
Co	15	0.061	0.015	0.003	0.37	0.36	0.094
Cr	15	0.083	0.012	0	0.55	0.55	0.15
Cu	15	0.027	0.005	0	0.1	0.1	0.033
F	15	0.12	0.10	0.06	0.3	0.24	0.059
Fe	15	0.036	0.019	0.004	0.2	0.2	0.051
K	15	5.7	2.3	1	20	19	7.4
Li	8	0.007	0.001	0	0.05	0.05	0.018
Mg	15	13	6.2	0.11	86	86	22
Mn	15	0.38	0.23	0.001	1.2	1.2	0.37
Mo	15	0.054	0.012	0.001	0.44	0.44	0.11
Na	15	3.4	3.6	0.003	6.0	6.0	1.5
Ni	14	0.11	0.023	0.007	0.72	0.71	0.2
pH[2]	15	6.42	6.39	5.68	7.24	1.56	0.43
Si	15	14	8.6	5.1	33	28	9.7
SO_4	15	130	55	29	660	630	170
Sp.Cond.[3]	15	320	230	100	1020	920	290
Sr	15	0.2	0.14	0.066	0.75	0.68	0.18
TDS	15	320	160	90	1330	1240	340
Ti	15	0.13	0.012	0.001	0.8	0.8	0.23
TIC	3	13	14	1	23	22	11
TOC	5	7.2	7.7	4.3	10	5.7	2.5
V	15	0.04	0.009	0.001	0.17	0.17	0.056
Zn	15	0.15	0.054	0.006	1.1	1	0.27

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[1] Concentrations are in mg/L unless otherwise noted.

[2] Units are standard pH units.

[3] Units are micromhos/cm.

TABLE E-58. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING EXXON PFBC WASTE AND SHALE

	Disposal Media Only		Waste and Disposal Media		
Element Species	Laboratory Control Column (Column B)	Field Control Cell (Cell 7)	Field Cell 1	Field Cell 2	Laboratory Leaching Column (Column 5)
Al	4.7	0.21	1.6	1.7	0.7
B	0.94	1.6	3.0	3.5	5.4
Ba	0.11	0.25	0.19	0.23	0.95
Ca	620	1000	550	550	340
Cd	0.01	0.04	0.01	0.01	0.01
Cl	240	1.4	20	29	19
Co	0.28	0.08	0.03	0.03	0.02
Cr	0.19	0.15	0.04	0.04	0.04
Cu	0.15	0.1	0.02	0.02	0.04
F	0.14	0.19	0.22	0.2	0.32
Fe	0.43	0.07	0.04	0.07	0.32
K	89	65	290	330	60
Li	0.36	0.03	0.09	0.18	0.04
Mg	460	210	200	180	63
Mn	21	0.08	0.05	0.05	0.77
Mo	0.14	0.09	0.05	0.05	0.11
Na	16	6.1	190	110	160
Ni	0.19	0.14	0.04	0.04	0.04
Si	10	15	15	14	11
SO_4	2600	2060	2760	2480	1800
Sr	2.0	1.8	1.5	1.4	0.83
TDS	4500	3670	4810	4420	2800
Ti	0.38	0.19	0.11	0.1	0.09
TIC	–	75	54	58	30
TOC	3	8.9	8.0	11	–
V	0.31	0.25	0.19	0.19	0.07
Zn	0.28	0.3	0.2	0.21	0.18

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-59. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING EXXON PFBC WASTE AND SANDSTONE

Element/ Species	Disposal Media Only Lab Control Column (Column A)	Waste and Disposal Media Field Cell 6
Al	2.6	2.8
B	0.59	3.8
Ba	0.12	0.23
Ca	710	500
Cd	0.01	0.01
Cl	2.5	16
Co	0.04	0.03
Cr	0.1	0.06
Cu	0.06	0.04
F	0.09	0.34
Fe	1.2	0.05
Li	0.01	0.85
Mg	230	310
Mn	0.80	3.0
Mo	0.07	0.08
Na	30	110
Ni	0.04	0.09
Si	12	13
SO_4	2000	3150
Sr	1.6	1.7
TDS	3400	5290
Ti	0.16	0.18
TIC	–	56
TOC	4.1	4.0
V	0.15	0.31
Zn	0.08	0.36

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-60. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING EXXON PFBC WASTE AND GLACIAL TILL

Element/ Species	Disposal Media Only Lab Control Column (Column F)	Waste and Disposal Media Field Cell 3
Al	1.6	1.7
B	0.97	3.3
Ba	0.24	0.28
Ca	160	500
Cd	0.011	0.01
Cl	4.4	17
Co	0.09	0.02
Cr	0.15	0.04
Cu	0.12	0.02
F	0.41	0.48
Fe	1.2	0.04
Li	0.003	0.26
K	11	54
Mg	62	190
Mn	0.76	0.06
Mo	0.12	0.06
Na	27	160
Ni	0.19	0.04
Si	29	22
SO_4	560	2050
Sr	0.18	0.4
TDS	750	3660
Ti	0.35	0.12
TIC	-	59
TOC	25	19
V	0.26	0.23
Zn	0.27	0.22

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-61. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING EXXON PFBC WASTE AND ALLUVIUM

	Disposal Media Only		Waste and Disposal Media
Element/ Species	Lab Control Column (Column C)	Field Control Cell (Cell 12)	Field Cell 5
Al	1.3	0.69	1.5
B	0.67	0.61	3
Ba	0.15	0.32	0.22
Ca	11	79	340
Cd	0.01	0.033	0.01
Cl	1.0	1.0	14
Co	0.086	0.061	0.03
Cr	0.13	0.083	0.05
Cu	0.12	0.027	0.04
F	0.07	0.12	0.23
Fe	2.7	0.036	0.05
K	3.8	5.7	230
Li	0.005	0.007	0.11
Mg	3.6	13	72
Mn	0.27	0.38	4.6
Mo	0.09	0.054	0.08
Na	4.0	3.4	190
Ni	0.02	0.11	0.13
Si	10	13	15
SO_4	31	130	2150
Sr	0.078	0.2	0.8
TDS	160	320	3610
Ti	0.33	0.13	0.15
TIC	–	12	1.0
TOC	5.0	7.2	5.0
V	0.23	0.04	0.17
Zn	0.017	0.15	0.31

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-62. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING EXXON PFBC WASTE AND LIMESTONE

	Disposal Media Only	Waste and Disposal Media
Element/ Species	Lab Control Column (Column E)	Field Cell 4
Al	1.8	1.5
B	1.6	3.9
Ba	0.27	0.22
Ca	150	480
Cd	0.01	0.02
Cl	1.5	7.1
Co	0.08	0.03
Cr	0.15	0.05
Cu	0.12	0.02
F	1.6	1.2
Fe	0.6	0.08
K	31	270
Li	0.14	0.62
Mg	67	140
Mn	0.1	0.17
Mo	0.94	0.36
Na	110	190
Ni	0.01	0.13
Si	22	17
SO	680	2580
Sr	7.3	7.5
TDS	1300	4770
Ti	0.34	0.16
TIC	–	58
TOC	3.5	7.8
V	0.25	0.2
Zn	0.02	0.32

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-63. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING ALLIANCE AFBC WASTE AND SHALE

	Disposal Media Only		Waste and Disposal Media
Element/ Species	Lab Control Column (Column B)	Field Control Cell (Cell 7)	Field Cell 17
Al	4.7	2.1	10
B	0.94	1.7	13
Ba	0.11	0.25	0.26
Ca	620	1000	680
Cd	0.01	0.04	0.02
Cl	2.4	1.4	140
Co	0.28	0.08	0.02
Cr	0.19	0.15	0.04
Cu	0.15	0.1	0.03
F	0.14	0.19	0.16
Fe	0.43	0.07	0.18
K	89	65	65
Li	0.36	0.03	0.04
Mg	460	210	240
Mn	21	0.08	0.25
Mo	0.14	0.09	0.02
Na	16	6.1	100
Ni	0.19	0.14	0.05
Si	10	15	9.9
SO_4	2600	2060	2070
Sr	2.0	1.8	3.8
TDS	4500	3670	4000
Ti	0.38	0.19	0.05
TIC	-	75	60
TOC	3.0	8.9	18
V	0.31	0.25	0.06
Zn	0.08	0.3	0.08

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-64. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING ALLIANCE AFBC WASTE AND INTERBURDEN

Element/ Species	Disposal Media Only Lab Control Column (Column D)	Waste and Disposal Media Field Cell 13
Al	1300	521
B	4.8	38
Ba	0.1	0.2
Ca	540	520
Cd	1.1	0.3
Cl	8.9	38
Co	12	4.0
Cr	1.3	0.3
Cu	2.3	8.0
F	4.1	3.5
Fe	4400	1050
K	110	110
Li	10	3.6
Mg	860	310
Mn	26	8.8
Mo	0.7	0.2
Na	35	46
Ni	24	9.1
Si	110	98
SO_4	23000	9420
Sr	0.7	7.5
TDS	38000	13160
Ti	0.3	0
TIC	–	1.0
TOC	2.5	–
V	0.6	0.3
Zn	58	17

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-65. LABORATORY COLUMN LEACHATE CONCENTRATIONS FOR CELLS CONTAINING ALLIANCE AFBC WASTE AND SANDSTONE

Element/ Species	Waste and Disposal Media Laboratory Leaching Column (Column 4)
Al	0.44
B	3.6
Ba	0.78
Ca	510
Cd	0.01
Cl	25
Co	0.01
Cr	0.02
Cu	0.02
F	0.47
Fe	0.23
K	130
Li	0.19
Mg	42
Mn	0.78
Mo	0.09
Na	57
Ni	0.01
Si	6.1
SO_4	970
Sr	1.5
TDS	1500
Ti	0.04
TIC	36
TOC	-
V	0.02
Zn	0.13

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-66. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING ALLIANCE AFBC WASTE AND ALLUVIUM

	Disposal Media Only		Waste and Disposal Media	
Element/ Species	Lab Control Column (Column C)	Field Control Cell (Cell 12)	Field Cell 14	Field Cell 15
Al	1.3	0.65	4	2.5
B	0.67	0.61	8.3	9.7
Ba	0.15	0.32	0.47	0.59
Ca	11	79	240	200
Cd	0.01	0.03	0.01	0.01
Cl	1.0	1.0	320	350
Co	0.086	0.06	0.01	0.01
Cr	0.13	0.08	0.02	0.01
Cu	0.12	0.03	0.01	0
F	0.07	0.12	0.15	0.12
Fe	2.7	0.04	0.72	0.07
K	3.8	5.7	9.6	8.9
Li	0.005	0.007	0	0
Mg	3.6	13	56	49
Mn	0.27	0.38	0.96	1.2
Mo	0.09	0.05	0	0
Na	4.0	3.4	92	53
Ni	0.02	0.11	0.05	0.05
Si	10	14	9.8	9.5
SO_4	31	130	430	220
Sr	0.078	0.2	0.85	0.83
TDS	160	320	1680	1380
Ti	0.33	0.13	0.01	0.01
TIC	–	13	1.0	1.0
TOC	5.0	7.2	10	5.7
V	0.23	0.04	0.01	0.02
Zn	0.017	0.15	0.12	0.11

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

TABLE E-67. COMPARISON OF LABORATORY COLUMN AND FIELD CELL LEACHATE CONCENTRATIONS FOR CELLS CONTAINING ALLIANCE AFBC WASTE AND LIMESTONE

Element/ Species	Disposal Media Only Lab Control Column (Column C)	Waste and Disposal Media Field Cell 16
Al	1.8	5.6
B	1.6	13
Ba	0.27	0.41
Ca	150	390
Cd	0.01	0.01
Cl	1.5	99
Co	0.08	0.02
Cr	0.15	0.02
Cu	0.12	0.02
F	1.6	1.3
Fe	0.6	0.05
K	31	320
Li	0.14	2.0
Mg	67	140
Mn	0.1	0.18
Mo	0.94	1.0
Na	110	240
Ni	0.01	0.06
Si	22	20
SO_4	680	1860
Sr	7.3	12
TDS	1300	3720
Ti	0.34	0.05
TIC	–	55
TOC	3.5	41
V	0.25	0.04
Zn	0.02	0.09

NOTE: Data for all columns are mean concentrations (mg/L) of samples collected after approximately 60 days of operation.

typically higher in the waste cell effluent for all cells than the media control cell effluents. Typically, chloride, potassium and sodium were elevated in waste-containing cell leachates. Some additional species showed variable behavior depending upon the medium, usually showing high concentrations from the shale and sandstone media. Examples are magnesium, manganese, and iron.

While the trace metals, Co, Cu, Cr, Ni, Ti, V, and Zn, were generally low in all cases, more often than not, the higher concentrations were found in the media-bearing column leachates.

For the Alliance AFBC waste cells, the interburden (alone and in conjunction with the waste) was atypical in behavior as might be expected with the pyrite oxidation and attendant acid release. Extremely high iron and sulfate levels resulted in both control and waste columns (higher for the former) with coincident high trace metals levels and very high aluminum. As for the Exxon system, the shale control columns had higher calcium and sulfate values than the waste-containing column. In all cases, the waste cells yielded elevated aluminum concentrations (unlike the Exxon system) and boron, chloride and sodium levels. In most cases, potassium and magnesium were also higher than for the control columns. While not consistently the case, the trace metals were generally lower for the waste cells than for the media columns.

While specific differences are present, the two wastes behave in similar fashion with respect to the disposal media they have in common. Excluding the interburden, highest leachate concentrations were found in the shale and sandstone control media leachates. These concentrations frequently exceeded those of the waste-containing cells.

E.10 References

E-1. Black, C.A., ed., 1965, Methods of Soil Analysis, Part 1, Agronomy Series 9, pp. 197-208, American Society of Agronomy, Inc.

Appendix E

Attachment 1

Tables E-9 to E-16

TABLE E-9. THROUGHPUT VOLUMES FOR FIELD CELL 1 (EXXON PFBC WASTE AND SHALE)

DATE	DAY(A)	DAY(D)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	0.20	0.20
06AUG79	2	2	18.06	18.26
07AUG79	3	3	17.98	36.23
08AUG79	4	4	2.21	38.44
11AUG79	7	7	10.66	49.10
12AUG79	8	8	10.16	59.26
14AUG79	10	10	11.77	71.03
16AUG79	12	12	13.41	84.45
19AUG79	15	15	4.62	89.07
24AUG79	20	20	4.54	93.61
28AUG79	24	24	20.76	114.38
02SEP79	29	29	23.26	137.64
09SEP79	36	36	11.16	148.80
20SEP79	47	47	9.57	158.37
29SEP79	56	56	50.86	209.23
14OCT79	71	71	84.36	293.59
01NOV79	89	89	32.43	326.02
04NOV79	92	92	4.35	330.37
24NOV79	112	112	20.87	351.24
14DEC79	132	132	44.20	395.44
17JAN80	166	166	71.20	466.64
06MAR80	215	215	55.13	521.76
31MAR80	240	240	94.00	615.76
28APR80	268	268	95.10	710.87
22MAY80	292	292	35.00	745.87
13JUN80	314	314	34.00	779.87
29JUN80	330	330	73.15	853.02
08AUG80	370	370	104.50	957.52
26AUG80	388	388	47.00	1004.52
11SEP80	404	404	89.89	1094.41
20OCT80	443	443	39.00	1133.41
20DEC80	504	504	109.00	1242.41
26DEC80	510	510	33.63	1276.05
17JUN81	683	548	42.11	1318.16
28JUN81	694	559	28.10	1346.26
15JUL81	711	576	48.00	1394.26
17JUL81	713	578	2.14	1396.40
10AUG81	737	602	64.20	1460.60
15AUG81	742	607	9.00	1469.60
17AUG81	744	609	1.70	1471.30
09SEP81	767	632	35.50	1506.80
15SEP81	773	638	0.00	1506.80
17SEP81	775	640	1.94	1508.74
07OCT81	795	660	16.00	1524.74
19OCT81	807	672	2.15	1526.89
06NOV81	825	690	2.15	1529.04

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TABLE E-10. THROUGHPUT VOLUMES FOR FIELD CELL 2 (EXXON PFBC WASTE AND SHALE)

DATE	DAY(A)	DAY(D)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	1.05	1.05
06AUG79	2	2	19.46	20.51
07AUG79	3	3	0.75	21.26
08AUG79	4	4	1.89	23.15
11AUG79	7	7	4.62	27.77
12AUG79	8	8	27.89	55.67
14AUG79	10	10	25.00	80.67
16AUG79	12	12	24.14	104.81
19AUG79	15	15	11.95	116.76
24AUG79	20	20	9.55	126.32
28AUG79	24	24	12.56	138.88
02SEP79	29	29	22.76	161.64
09SEP79	36	36	11.46	173.11
20SEP79	47	47	10.60	183.71
29SEP79	56	56	49.75	233.46
14OCT79	71	71	83.55	317.01
01NOV79	89	89	18.76	335.77
04NOV79	92	92	3.66	339.43
24NOV79	112	112	22.73	362.16
14DEC79	132	132	43.05	405.22
17JAN80	166	166	77.23	482.45
06MAR80	215	215	51.22	533.67
31MAR80	240	240	76.00	609.67
28APR80	268	268	93.12	702.79
22MAY80	292	292	49.00	751.79
13JUN80	314	314	51.00	802.79
29JUN80	330	330	80.79	883.58
08AUG80	370	370	104.50	988.08
26AUG80	388	388	60.00	1048.08
11SEP80	404	404	80.07	1128.15
20OCT80	443	443	40.00	1168.15
20DEC80	504	504	107.00	1275.15
26DEC80	510	510	23.49	1298.64
17JUN81	683	548	56.13	1354.77
28JUN81	694	559	64.10	1418.87
15JUL81	711	576	58.00	1476.87
17JUL81	713	578	2.12	1478.99
22JUL81	718	583	9.00	1487.99
23JUL81	719	584	3.50	1491.49
10AUG81	737	602	131.20	1622.69
15AUG81	742	607	50.00	1672.69
17AUG81	744	609	2.11	1674.80
09SEP81	767	632	90.50	1765.30
15SEP81	773	638	8.00	1773.30
17SEP81	775	640	2.16	1775.46
07OCT81	795	660	41.00	1816.46
19OCT81	807	672	2.15	1818.61

TABLE E-11. THROUGHPUT VOLUMES FOR FIELD CELL 3 (EXXON PFBC WASTE AND GLACIAL TILL)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	0.59	0.59
06AUG79	2	2	0.57	1.16
07AUG79	3	3	5.58	6.74
08AUG79	4	4	0.03	6.77
11AUG79	7	7	1.12	7.89
12AUG79	8	8	4.86	12.75
14AUG79	10	10	8.56	21.31
16AUG79	12	12	8.93	30.24
19AUG79	15	15	10.45	40.69
24AUG79	20	20	11.25	51.94
28AUG79	24	24	6.06	58.00
02SEP79	29	29	8.36	66.36
09SEP79	36	36	12.76	79.12
20SEP79	47	47	14.36	93.48
29SEP79	56	56	21.06	114.54
14OCT79	71	71	54.35	168.89
01NOV79	89	89	57.86	226.75
04NOV79	92	92	8.07	234.82
24NOV79	112	112	25.13	259.95
14DEC79	132	132	36.12	296.08
17JAN80	166	166	61.12	357.20
06MAR80	215	215	56.13	413.33
31MAR80	240	240	70.00	483.33
28APR80	268	268	93.11	576.44
22MAY80	292	292	17.00	593.44
13JUN80	314	314	10.00	603.44
29JUN80	330	330	68.63	672.07
08AUG80	370	370	107.50	779.57
26AUG80	388	388	54.00	833.57
11SEP80	404	404	81.43	915.00
20OCT80	443	443	29.00	944.00
20DEC80	504	504	113.00	1057.00
26DEC80	510	510	22.10	1079.10
17JUN81	683	548	27.12	1106.22
28JUN81	694	559	66.10	1172.32
15JUL81	711	576	49.00	1221.32
17JUL81	713	578	1.48	1222.80
10AUG81	737	602	66.20	1289.00
15AUG81	742	607	10.00	1299.00
17AUG81	744	609	1.29	1300.29
09SEP81	767	632	40.50	1340.79
15SEP81	773	638	3.00	1343.79
17SEP81	775	640	1.71	1345.50
07OCT81	795	660	26.00	1371.50
19OCT81	807	672	1.51	1373.01

TABLE E-12. THROUGHPUT VOLUMES FOR FIELD CELL 4 (EXXON PFBC WASTE AND LIMESTONE)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	22.95	22.95
06AUG79	2	2	29.36	52.31
07AUG79	3	3	9.53	61.84
08AUG79	4	4	3.39	65.23
11AUG79	7	7	10.36	75.59
12AUG79	8	8	12.74	88.33
14AUG79	10	10	20.44	108.77
16AUG79	12	12	9.37	118.14
19AUG79	15	15	12.34	130.48
24AUG79	20	20	16.53	147.02
28AUG79	24	24	18.35	165.37
02SEP79	29	29	20.14	185.51
09SEP79	36	36	22.35	207.86
20SEP79	47	47	14.89	222.75
29SEP79	56	56	28.34	251.09
14OCT79	71	71	57.33	308.43
01NOV79	89	89	35.05	343.48
04NOV79	92	92	5.45	348.93
24NOV79	112	112	44.57	393.50
14DEC79	132	132	35.39	428.89
17JAN80	166	165	69.06	497.95
06MAR80	215	215	96.32	594.27
31MAR80	240	240	43.00	637.27
28APR80	268	268	79.10	716.37
22MAY80	292	292	49.00	765.37
13JUN80	314	314	10.00	775.37
29JUN80	330	330	52.13	827.51
08AUG80	370	370	106.50	934.01
26AUG80	388	388	5.00	939.01
11SEP80	404	404	79.66	1018.67
20OCT80	443	443	49.00	1067.67
20DEC80	504	504	107.00	1174.67
26DEC80	510	510	32.62	1207.29
17JUN81	683	548	31.11	1238.40
28JUN81	694	559	94.10	1332.50
15JUL81	711	576	78.00	1410.50
17JUL81	713	578	2.06	1412.56
10AUG81	737	602	92.20	1504.76
15AUG81	742	607	15.00	1519.76
17AUG81	744	609	1.58	1521.34
09SEP81	767	632	20.50	1541.84
15SEP81	773	638	5.00	1546.84
17SEP81	775	640	2.14	1548.98
07OCT81	795	660	50.00	1598.98
19OCT81	807	672	2.13	1601.11
06NOV81	825	690	2.16	1603.27

TABLE E-13. THROUGHPUT VOLUMES FOR FIELD CELL 5 (EXXON PFBC WASTE AND ALLUVIUM)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	0.56	0.56
06AUG79	2	2	3.56	4.12
07AUG79	3	3	8.06	12.18
08AUG79	4	4	2.23	14.41
11AUG79	7	7	9.88	24.29
12AUG79	8	8	6.43	30.72
14AUG79	10	10	15.05	45.77
16AUG79	12	12	18.20	63.97
19AUG79	15	15	21.87	85.84
24AUG79	20	20	22.54	108.39
28AUG79	24	24	12.11	120.50
02SEP79	29	29	12.16	132.65
09SEP79	36	36	19.26	151.92
20SEP79	47	47	11.20	163.12
29SEP79	56	56	21.35	184.48
14OCT79	71	71	58.66	243.14
01NOV79	89	89	60.86	304.00
04NOV79	92	92	4.77	308.77
24NOV79	112	112	13.21	321.98
14DEC79	132	132	36.35	358.33
17JAN80	166	166	58.48	416.82
06MAR80	215	215	55.54	472.36
31MAR80	240	240	43.00	515.36
28APR80	268	268	67.10	582.46
22MAY80	292	292	41.00	623.46
13JUN80	314	314	10.00	633.46
29JUN80	330	330	59.14	692.60
08AUG80	370	370	107.50	800.10
26AUG80	388	388	24.00	824.10
11SEP80	404	404	65.23	889.33
20OCT80	443	443	32.00	921.33
20DEC80	504	504	108.00	1029.33
26DEC80	510	510	31.01	1060.34
17JUN81	683	548	20.62	1080.97
28JUN81	694	559	56.10	1137.07
15JUL81	711	576	87.00	1224.07
17JUL81	713	578	1.24	1225.31
22JUL81	718	583	5.00	1230.31
23JUL81	719	584	1.00	1231.31
10AUG81	737	602	88.20	1319.51
15AUG81	742	607	26.00	1345.51
17AUG81	744	609	1.36	1346.87
09SEP81	767	632	86.50	1433.37
15SEP81	773	638	2.00	1435.37
17SEP81	775	640	0.80	1436.17
07OCT81	795	660	14.00	1450.17
19OCT81	807	672	1.48	1451.66

TABLE E-14. THROUGHPUT VOLUMES FOR FIELD CELL 6 (EXXON PFBC WASTE AND SANDSTONE)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	12.84	12.84
06AUG79	2	2	13.86	26.70
07AUG79	3	3	8.85	35.55
08AUG79	4	4	2.51	38.07
11AUG79	7	7	8.46	46.53
12AUG79	8	8	6.05	52.58
14AUG79	10	10	16.44	69.02
16AUG79	12	12	11.75	80.78
19AUG79	15	15	14.14	94.92
24AUG79	20	20	16.64	111.57
28AUG79	24	24	10.25	121.82
02SEP79	29	29	10.35	132.17
09SEP79	36	36	14.35	146.52
20SEP79	47	47	17.64	164.17
29SEP79	56	56	17.65	181.82
14OCT79	71	71	29.35	211.17
01NOV79	89	89	32.08	243.25
04NOV79	92	92	5.83	249.08
24NOV79	112	112	41.86	290.95
14DEC79	132	132	39.42	330.37
17JAN80	166	166	72.52	402.89
06MAR80	215	215	72.13	475.02
31MAR80	240	240	56.00	531.02
28APR80	268	268	85.11	616.13
22MAY80	292	292	68.00	684.13
13JUN80	314	314	30.00	714.13
29JUN80	330	330	59.03	773.16
08AUG80	370	370	108.50	881.66
26AUG80	388	388	53.00	934.66
11SEP80	404	404	82.52	1017.18
20OCT80	443	443	36.00	1053.18
20DEC80	504	504	108.00	1161.18
26DEC80	510	510	25.34	1186.52
17JUN81	683	548	70.13	1256.65
28JUN81	694	559	64.10	1320.75
15JUL81	711	576	57.00	1377.75
17JUL81	713	578	2.00	1379.75
10AUG81	737	602	74.20	1453.95
15AUG81	742	607	11.00	1464.95
17AUG81	744	609	1.57	1466.52
09SEP81	767	632	20.50	1487.02
15SEP81	773	638	2.00	1489.02
17SEP81	775	640	2.16	1491.18
07OCT81	795	660	33.00	1524.18
19OCT81	807	672	1.89	1526.08
06NOV81	825	690	2.16	1528.24

TABLE E-15. THROUGHPUT VOLUMES FOR FIELD CELL 7 (SHALE CONTROL)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	13.91	13.91
06AUG79	2	2	16.53	30.44
07AUG79	3	3	13.03	43.47
08AUG79	4	4	1.69	45.17
11AUG79	7	7	11.83	57.00
12AUG79	8	8	10.34	67.34
14AUG79	10	10	19.63	86.97
16AUG79	12	12	12.73	99.70
19AUG79	15	15	14.84	114.54
24AUG79	20	20	16.93	131.47
28AUG79	24	24	18.23	149.70
02SEP79	29	29	25.83	175.53
09SEP79	36	36	15.23	190.76
20SEP79	47	47	16.82	207.58
29SEP79	56	56	52.82	260.40
14OCT79	71	71	83.12	343.53
01NOV79	89	89	35.14	378.67
04NOV79	92	92	3.10	381.77
24NOV79	112	112	21.34	403.11
14DEC79	132	132	50.28	453.39
17JAN80	166	166	77.04	530.43
06MAR80	215	215	65.06	595.50
31MAR80	240	240	88.00	683.50
28APR80	268	268	93.07	776.57
22MAY80	292	292	45.00	821.57
13JUN80	314	314	82.00	903.57
29JUN80	330	330	43.06	946.63
08AUG80	370	370	106.00	1052.63
26AUG80	388	388	53.00	1105.63
11SEP80	404	404	26.07	1131.70
20OCT80	443	443	25.00	1156.70
20DEC80	504	504	118.00	1274.70
26DEC80	510	510	6.57	1281.27
17JUN81	683	548	31.08	1312.35
28JUN81	694	559	33.50	1345.85
15JUL81	711	576	52.00	1397.85
17JUL81	713	578	1.09	1398.95
10AUG81	737	602	74.00	1472.95
15AUG81	742	607	13.00	1485.95
17AUG81	744	609	0.79	1486.74
09SEP81	767	632	17.00	1503.74
15SEP81	773	638	4.00	1507.74
17SEP81	775	640	1.09	1508.83
07OCT81	795	660	48.00	1556.83
19OCT81	807	672	1.06	1557.89
06NOV81	825	690	1.09	1558.98

TABLE E-16. THROUGHPUT VOLUMES FOR FIELD CELL 12 (ALLUVIUM CONTROL)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
04AUG79	0	0	7.65	7.65
06AUG79	2	2	10.03	17.68
07AUG79	3	3	10.33	28.01
08AUG79	4	4	2.61	30.62
11AUG79	7	7	8.42	39.05
12AUG79	8	8	5.43	44.48
14AUG79	10	10	14.23	58.71
16AUG79	12	12	9.61	68.32
19AUG79	15	15	12.62	80.94
24AUG79	20	20	14.83	95.78
28AUG79	24	24	19.23	115.01
02SEP79	29	29	21.83	136.84
09SEP79	36	36	24.93	161.77
20SEP79	47	47	27.45	189.22
29SEP79	56	56	20.50	209.72
14OCT79	71	71	51.62	261.34
01NOV79	89	89	46.94	308.28
04NOV79	92	92	3.78	312.06
24NOV79	112	112	25.23	337.29
14DEC79	132	132	19.45	356.74
17JAN80	166	166	44.81	401.56
06MAR80	215	215	49.08	450.63
31MAR80	240	240	25.00	475.63
28APR80	268	268	43.08	518.71
22MAY80	292	292	37.00	555.71
13JUN80	314	314	69.00	624.71
29JUN80	330	330	36.06	660.78
08AUG80	370	370	108.00	768.78
26AUG80	388	388	60.00	828.78
11SEP80	404	404	11.79	840.57
20OCT80	443	443	20.00	860.57
20DEC80	504	504	126.00	986.57
26DEC80	510	510	19.56	1006.13
17JUN81	683	548	29.09	1035.22
28JUN81	694	559	31.50	1066.72
15JUL81	711	576	34.00	1100.72
17JUL81	713	578	0.63	1101.35
10AUG81	737	602	38.00	1139.35
15AUG81	742	607	7.00	1146.35
17AUG81	744	609	0.68	1147.03
09SEP81	767	632	23.00	1170.03
15SEP81	773	638	4.00	1174.03
17SEP81	775	640	0.65	1174.68
07OCT81	795	660	19.00	1193.68
19OCT81	807	672	1.09	1194.77
06NOV81	825	690	1.08	1195.85

Appendix E

Attachment 2

Tables E-19 to E-23

TABLE E-19. THROUGHPUT VOLUMES FOR FIELD CELL 13 (ALLIANCE AFBC WASTE AND INTERBURDEN)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
21MAR80	0	0	35.12	35.12
22MAR80	1	1	9.72	44.84
23MAR80	2	2	7.54	52.39
24MAR80	3	3	2.84	55.23
26MAR80	5	5	2.48	57.70
28MAR80	7	7	1.19	58.90
31MAR80	10	10	2.35	61.25
04APR80	14	14	10.13	71.38
10APR80	20	20	10.66	82.04
19APR80	29	29	25.14	107.18
12MAY80	52	52	10.01	117.19
20MAY80	60	60	2.82	120.01
29MAY80	69	69	78.00	198.01
12JUN80	83	83	93.09	291.10
23JUL80	124	124	94.12	385.23
26AUG80	158	158	110.00	495.23
03SEP80	166	166	41.74	536.96
20OCT80	213	213	19.49	556.45
28NOV80	252	252	39.34	595.79
16JAN81	301	301	42.00	637.79
30JAN81	315	315	44.00	681.79
03FEB81	319	319	1.60	683.40
01APR81	376	376	105.00	788.40
24APR81	399	399	44.09	832.49
12MAY81	417	417	53.00	885.49
15JUN81	451	451	95.00	980.49
15JUN81	451	451	78.00	1058.49
18JUN81	454	454	36.14	1094.63
28JUN81	464	464	42.00	1136.63
15JUL81	481	481	58.00	1194.63
17JUL81	483	483	1.14	1195.77
10AUG81	507	507	56.00	1251.77
15AUG81	512	512	7.00	1258.77
17AUG81	514	514	0.93	1259.70
09SEP81	537	537	40.00	1299.70
15SEP81	543	543	3.00	1302.70
17SEP81	545	545	2.02	1304.72
07OCT81	565	565	20.00	1324.72
19OCT81	577	577	1.12	1325.85

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TABLE E-20. THROUGHPUT VOLUMES FOR FIELD CELL 14 (ALLIANCE AFBC WASTE AND ALLUVIUM)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
21MAR80	0	0	0.00	0.00
22MAR80	1	1	0.01	0.01
23MAR80	2	2	0.00	0.01
24MAR80	3	3	0.11	0.12
26MAR80	5	5	0.40	0.52
28MAR80	7	7	0.58	1.11
31MAR80	10	10	12.68	13.79
04APR80	14	14	29.82	43.60
10APR80	20	20	19.95	63.55
19APR80	29	29	30.15	93.70
12MAY80	52	52	21.08	114.79
20MAY80	60	60	2.26	117.05
29MAY80	69	69	110.00	227.05
12JUN80	83	83	35.22	262.27
23JUL80	124	124	77.76	340.02
26AUG80	158	158	91.00	431.02
03SEP80	166	166	98.15	529.17
20OCT80	213	213	65.92	595.09
28NOV80	252	252	8.23	603.32
16JAN81	301	301	39.00	642.32
30JAN81	315	315	38.00	680.32
03FEB81	319	319	1.49	681.82
01APR81	376	376	53.00	734.82
24APR81	399	399	65.46	800.28
12MAY81	417	417	45.00	845.28
15JUN81	451	451	91.00	936.28
15JUN81	451	451	17.25	953.53
18JUN81	454	454	9.00	962.53
28JUN81	464	464	28.00	990.53
15JUL81	481	481	55.00	1045.53
17JUL81	483	483	1.34	1046.87
22JUL81	488	488	13.00	1059.87
23JUL81	489	489	2.00	1061.87
10AUG81	507	507	53.00	1114.87
15AUG81	512	512	15.00	1129.87
17AUG81	514	514	1.16	1131.03
09SEP81	537	537	48.00	1179.03
15SEP81	543	543	3.00	1182.03
17SEP81	545	545	0.77	1182.80
07OCT81	565	565	9.00	1191.80
19OCT81	577	577	1.43	1193.23

TABLE E-21. THROUGHPUT VOLUMES FOR FIELD CELL 15 (ALLIANCE AFBC WASTE AND ALLUVIUM)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
21MAR80	0	0	0.00	0.00
22MAR80	1	1	0.38	0.38
23MAR80	2	2	0.88	1.26
24MAR80	3	3	0.90	2.16
26MAR80	5	5	1.40	3.57
28MAR80	7	7	13.17	16.74
31MAR80	10	10	35.16	51.90
04APR80	14	14	37.17	89.07
10APR80	20	20	28.92	118.00
19APR80	29	29	28.15	146.15
12MAY80	52	52	26.37	172.52
20MAY80	60	60	4.32	176.84
29MAY80	69	69	107.00	283.84
12JUN80	83	83	4.91	288.75
23JUL80	124	124	28.91	317.67
26AUG80	158	158	96.00	413.67
03SEP80	166	166	52.45	466.12
20OCT80	213	213	36.74	502.86
28NOV80	252	252	26.29	529.15
16JAN81	301	301	9.00	538.15
30JAN81	315	315	22.00	560.15
03FEB81	319	319	1.75	561.90
01APR81	376	376	22.00	583.90
24APR81	399	399	31.34	615.24
12MAY81	417	417	20.00	635.24
15JUN81	451	451	93.00	728.24
15JUN81	451	451	17.25	745.49
18JUN81	454	454	10.00	755.49
29JUN81	464	464	24.00	779.49
15JUL81	481	481	25.00	804.49
17JUL81	483	483	1.06	805.55
10AUG81	507	507	33.00	838.55
15AUG81	512	512	8.00	846.55
17AUG81	514	514	0.98	847.53
09SEP81	537	537	17.00	864.53
15SEP81	543	543	3.00	867.53
17SEP81	545	545	0.50	868.03
07OCT81	565	565	4.00	872.03
19OCT81	577	577	1.08	873.11
06NOV81	595	595	0.57	873.68

TABLE E-22. THROUGHPUT VOLUMES FOR FIELD CELL 16 (ALLIANCE AFBC WASTE AND LIMESTONE)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
21MAR80	0	0	58.17	58.17
22MAR80	1	1	13.07	71.24
23MAR80	2	2	9.94	81.18
24MAR80	3	3	8.00	89.18
26MAR80	5	5	19.03	108.21
28MAR80	7	7	9.78	117.99
31MAR80	10	10	10.58	128.57
04APR80	14	14	15.17	143.74
10APR80	20	20	10.53	154.27
19APR80	29	29	26.16	180.43
12MAY80	52	52	20.55	200.98
20MAY80	60	60	4.40	205.38
29MAY80	69	69	93.00	298.38
12JUN80	83	83	30.13	328.51
23JUL80	124	124	81.66	410.18
26AUG80	158	158	53.00	463.18
03SEP80	166	166	56.14	519.32
20OCT80	213	213	57.68	577.00
28NOV80	252	252	33.36	610.36
16JAN81	301	301	20.00	630.36
30JAN81	315	315	38.00	668.36
03FEB81	319	319	3.54	671.90
01APR81	376	376	13.00	684.90
24APR81	399	399	22.78	707.69
12MAY81	417	417	13.00	720.69
15JUN81	451	451	95.00	815.69
15JUN81	451	451	17.25	832.94
18JUN81	454	454	8.92	841.86
28JUN81	464	464	25.00	866.86
15JUL81	481	481	30.00	896.86
17JUL81	483	483	2.10	898.97
10AUG81	507	507	27.00	925.97
15AUG81	512	512	5.00	930.97
17AUG81	514	514	1.99	932.96
09SEP81	537	537	22.00	954.96
15SEP81	543	543	4.00	958.96
17SEP81	545	545	1.77	960.73
07OCT81	565	565	18.00	978.73
19OCT81	577	577	2.17	980.90
06NOV81	595	595	2.17	983.07

TABLE E-23. THROUGHPUT VOLUMES FOR FIELD CELL 17 (ALLIANCE AFBC WASTE AND SHALE)

DATE	DAY(A)	DAY(O)	FLOW-THROUGH VOLUME	CUMULATIVE VOLUME
21MAR80	0	0	73.16	73.16
22MAR80	1	1	11.40	84.57
23MAR80	2	2	11.10	95.67
24MAR80	3	3	8.41	104.08
26MAR80	5	5	11.26	115.35
28MAR80	7	7	6.38	121.73
31MAR80	10	10	11.91	133.64
04APR80	14	14	14.16	147.80
10APR80	20	20	13.11	160.91
19APR80	29	29	19.16	180.07
12MAY80	52	52	47.14	227.21
20MAY80	60	60	12.70	239.92
29MAY80	69	69	27.00	266.92
12JUN80	83	83	20.03	286.95
23JUL80	124	124	31.66	318.61
26AUG80	158	158	24.00	342.61
03SEP80	166	166	27.13	369.73
20OCT80	213	213	52.67	422.40
28NOV80	252	252	33.65	456.06
16JAN81	301	301	14.00	470.06
30JAN81	315	315	24.00	494.06
03FEB81	319	319	4.96	499.02
01APR81	376	376	18.00	517.02
24APR81	399	399	16.15	533.18
12MAY81	417	417	10.00	543.18
15JUN81	451	451	35.00	578.18
15JUN81	451	451	17.25	595.43
18JUN81	454	454	5.15	600.58
28JUN81	464	464	8.00	608.58
15JUL81	481	481	17.00	625.58
17JUL81	483	483	2.12	627.71
22JUL81	488	488	5.00	632.71
23JUL81	489	489	1.00	633.71
10AUG81	507	507	10.00	643.71
15AUG81	512	512	5.00	648.71
17AUG81	514	514	2.14	650.85
09SEP81	537	537	29.00	679.85
15SEP81	543	543	7.00	686.85
17SEP81	545	545	2.16	689.01
07OCT81	565	565	47.00	736.01
19OCT81	577	577	2.15	738.16

Appendix E

Attachment 3

Precipitation Record for the Exxon PFBC and Control (Media Only) Field Cells

Precipitation on the Exxon PFBC field cells (Cells 1 to 6) and the control (media-only) field cells (Cells 7 and 12) was measured with a ground-mounted, standard weighing rain gage. Daily precipitation totals were transcribed into the SAS data base and converted to column of water per cell (by calculating the area of the surface of each circular cell).

In the table of data, the elapsed days are split into two entities -- day (A) or actual days since field cell startup date, and day (O) or operational days which reflect the 135 days from 16 January 1981 to 7 June 1981 for which no precipitation data were collected. The PFBC and control cells were covered from 26 December 1980 to 1 June 1981. The large volume recorded on the first few sample days are a result of artificial irrigation as the cells were brought to field capacity before being put into operation.

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DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
01AUG79	0	0	177.85	177.85
02AUG79	1	1	0.00	177.85
03AUG79	2	2	59.28	237.13
04AUG79	3	3	59.28	296.42
05AUG79	4	4	1.46	297.87
06AUG79	5	5	1.46	299.33
07AUG79	6	6	0.00	299.33
08AUG79	7	7	10.19	309.53
09AUG79	8	8	0.00	309.53
10AUG79	9	9	23.67	333.19
11AUG79	10	10	22.76	355.95
12AUG79	11	11	9.65	365.60
13AUG79	12	12	0.00	365.60
14AUG79	13	13	2.37	367.96
15AUG79	14	14	0.00	367.96
16AUG79	15	15	0.00	367.96
17AUG79	16	16	0.00	367.96
18AUG79	17	17	18.02	385.99
19AUG79	18	18	0.00	385.99
20AUG79	19	19	1.82	387.81
21AUG79	20	20	1.46	389.26
22AUG79	21	21	0.91	390.17
23AUG79	22	22	7.46	397.64
24AUG79	23	23	5.46	403.10
25AUG79	24	24	0.00	403.10
26AUG79	25	25	0.00	403.10
27AUG79	26	26	21.01	424.11
28AUG79	27	27	0.00	424.11
29AUG79	28	28	16.34	440.44
30AUG79	29	29	0.00	440.44
31AUG79	30	30	0.00	440.44
01SEP79	31	31	0.00	440.44
02SEP79	32	32	0.00	440.44

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
03SEP79	33	33	9.34	449.78
04SEP79	34	34	0.00	449.78
05SEP79	35	35	0.00	449.78
06SEP79	36	36	18.67	468.45
07SEP79	37	37	0.00	468.45
08SEP79	38	38	0.00	468.45
09SEP79	39	39	0.00	468.45
10SEP79	40	40	0.00	468.45
11SEP79	41	41	0.00	468.45
12SEP79	42	42	0.00	468.45
13SEP79	43	43	0.00	468.45
14SEP79	44	44	15.17	483.62
15SEP79	45	45	0.00	483.62
16SEP79	46	46	0.00	483.62
17SEP79	47	47	0.00	483.62
18SEP79	48	48	0.00	483.62
19SEP79	49	49	5.83	489.46
20SEP79	50	50	0.00	489.46
21SEP79	51	51	33.84	523.30
22SEP79	52	52	17.50	540.81
23SEP79	53	53	2.33	543.14
24SEP79	54	54	0.00	543.14
25SEP79	55	55	0.00	543.14
26SEP79	56	56	0.00	543.14
27SEP79	57	57	0.00	543.14
28SEP79	58	58	9.34	552.48
29SEP79	59	59	31.51	583.99
30SEP79	60	60	1.17	585.15
01OCT79	61	61	0.00	585.15
02OCT79	62	62	0.00	585.15
03OCT79	63	63	19.84	604.99
04OCT79	64	64	0.00	604.99

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DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
05OCT79	65	65	5.83	610.83
06OCT79	66	66	4.67	615.49
07OCT79	67	67	8.17	623.66
08OCT79	68	68	1.17	624.83
09OCT79	69	69	10.50	635.33
10OCT79	70	70	12.84	648.17
11OCT79	71	71	2.33	650.50
12OCT79	72	72	8.17	658.67
13OCT79	73	73	12.84	671.51
14OCT79	74	74	0.00	671.51
15OCT79	75	75	0.00	671.51
16OCT79	76	76	0.00	671.51
17OCT79	77	77	0.00	671.51
18OCT79	78	78	0.00	671.51
19OCT79	79	79	0.00	671.51
20OCT79	80	80	0.00	671.51
21OCT79	81	81	0.00	671.51
22OCT79	82	82	0.00	671.51
23OCT79	83	83	0.00	671.51
24OCT79	84	84	0.00	671.51
25OCT79	85	85	0.00	671.51
26OCT79	86	86	0.00	671.51
27OCT79	87	87	0.00	671.51
28OCT79	88	88	2.33	673.84
29OCT79	89	89	0.00	673.84
30OCT79	90	90	0.00	673.84
31OCT79	91	91	0.00	673.84
01NOV79	92	92	0.00	673.84
02NOV79	93	93	12.84	686.68
03NOV79	94	94	0.00	686.68
04NOV79	95	95	0.00	686.68
05NOV79	96	96	0.00	686.68

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
06NOV79	97	97	0.00	686.68
07NOV79	98	98	1.17	687.85
08NOV79	99	99	0.00	687.85
09NOV79	100	100	4.67	692.52
10NOV79	101	101	0.00	692.52
11NOV79	102	102	0.00	692.52
12NOV79	103	103	0.00	692.52
13NOV79	104	104	0.00	692.52
14NOV79	105	105	0.00	692.52
15NOV79	106	106	0.00	692.52
16NOV79	107	107	1.17	693.68
17NOV79	108	108	0.00	693.68
18NOV79	109	109	0.00	693.68
19NOV79	110	110	0.00	693.68
20NOV79	111	111	0.00	693.68
21NOV79	112	112	0.00	693.68
22NOV79	113	113	0.00	693.68
23NOV79	114	114	0.00	693.68
24NOV79	115	115	16.34	710.02
25NOV79	116	116	0.00	710.02
26NOV79	117	117	29.17	739.20
27NOV79	118	118	0.00	739.20
28NOV79	119	119	0.00	739.20
29NOV79	120	120	0.00	739.20
30NOV79	121	121	0.00	739.20
01DEC79	122	122	0.00	739.20
02DEC79	123	123	0.00	739.20
03DEC79	124	124	0.00	739.20
04DEC79	125	125	0.00	739.20
05DEC79	126	126	0.00	739.20
06DEC79	127	127	0.00	739.20
07DEC79	128	128	0.00	739.20

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
08DEC79	129	129	0.00	739.20
09DEC79	130	130	0.00	739.20
10DEC79	131	131	0.00	739.20
11DEC79	132	132	0.00	739.20
12DEC79	133	133	25.67	764.87
13DEC79	134	134	14.00	778.87
14DEC79	135	135	0.00	778.87
14DEC79	135	135	0.00	778.87
15DEC79	136	136	0.00	778.87
16DEC79	137	137	0.00	778.87
17DEC79	138	138	0.00	778.87
18DEC79	139	139	0.00	778.87
19DEC79	140	140	0.00	778.87
20DEC79	141	141	0.00	778.87
21DEC79	142	142	0.00	778.87
22DEC79	143	143	0.00	778.87
23DEC79	144	144	0.00	778.87
24DEC79	145	145	24.51	803.38
25DEC79	146	146	0.00	803.38
26DEC79	147	147	0.00	803.38
27DEC79	148	148	0.00	803.38
28DEC79	149	149	0.00	803.38
29DEC79	150	150	0.00	803.38
30DEC79	151	151	0.00	803.38
31DEC79	152	152	0.00	803.38
01JAN80	153	153	0.00	803.38
02JAN80	154	154	0.00	803.38
03JAN80	155	155	0.00	803.38
04JAN80	156	156	0.00	803.38
05JAN80	157	157	0.00	803.38
06JAN80	158	158	0.00	803.38
07JAN80	159	159	10.50	813.88

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
08JAN80	160	160	1.17	815.05
09JAN80	161	161	1.17	816.22
10JAN80	162	162	3.50	819.72
11JAN80	163	163	11.67	831.39
12JAN80	164	164	0.00	831.39
13JAN80	165	165	0.00	831.39
14JAN80	166	166	8.17	839.56
15JAN80	167	167	0.00	839.56
16JAN80	168	168	0.00	839.56
17JAN80	169	169	7.00	846.56
18JAN80	170	170	0.00	846.56
19JAN80	171	171	0.00	846.56
20JAN80	172	172	0.00	846.56
21JAN80	173	173	0.00	846.56
22JAN80	174	174	0.00	846.56
23JAN80	175	175	0.00	846.56
24JAN80	176	176	0.00	846.56
25JAN80	177	177	11.67	858.23
26JAN80	178	178	0.00	858.23
27JAN80	179	179	0.00	858.23
28JAN80	180	180	0.00	858.23
29JAN80	181	181	0.00	858.23
30JAN80	182	182	0.00	858.23
31JAN80	183	183	0.00	858.23
01FEB80	184	184	0.00	858.23
02FEB80	185	185	0.00	858.23
03FEB80	186	186	0.00	858.23
04FEB80	187	187	0.00	858.23
05FEB80	188	188	2.33	860.56
06FEB80	189	189	0.00	860.56
07FEB80	190	190	0.00	860.56
08FEB80	191	191	0.00	860.56

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
09FEB80	192	192	0.00	860.56
10FEB80	193	193	0.00	860.56
11FEB80	194	194	0.00	860.56
12FEB80	195	195	0.00	860.56
13FEB80	196	196	0.00	860.56
14FEB80	197	197	0.00	860.56
15FEB80	198	198	0.00	860.56
16FEB80	199	199	7.00	867.57
17FEB80	200	200	0.00	867.57
18FEB80	201	201	0.00	867.57
19FEB80	202	202	0.00	867.57
20FEB80	203	203	2.33	869.90
21FEB80	204	204	8.17	878.07
22FEB80	205	205	5.83	883.90
23FEB80	206	206	4.67	888.57
24FEB80	207	207	0.00	888.57
25FEB80	208	208	0.00	888.57
26FEB80	209	209	0.00	888.57
27FEB80	210	210	0.00	888.57
28FEB80	211	211	2.33	890.91
29FEB80	212	212	0.00	890.91
01MAR80	213	213	0.00	890.91
02MAR80	214	214	0.00	890.91
03MAR80	215	215	0.00	890.91
04MAR80	216	216	4.67	895.57
05MAR80	217	217	21.01	916.58
06MAR80	218	218	0.00	916.58
07MAR80	219	219	0.00	916.58
08MAR80	220	220	11.67	928.25
09MAR80	221	221	0.00	928.25
10MAR80	222	222	2.33	930.58
11MAR80	223	223	0.00	930.58

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
12MAR80	224	224	0.00	930.58
13MAR80	225	225	5.83	936.42
14MAR80	226	226	5.83	942.25
15MAR80	227	227	9.34	951.59
16MAR80	228	228	0.00	951.59
17MAR80	229	229	17.50	969.10
18MAR80	230	230	2.33	971.43
19MAR80	231	231	0.00	971.43
20MAR80	232	232	0.00	971.43
21MAR80	233	233	8.17	979.60
22MAR80	234	234	0.00	979.60
23MAR80	235	235	0.00	979.60
24MAR80	236	236	7.00	986.60
25MAR80	237	237	0.00	986.60
26MAR80	238	238	0.00	986.60
27MAR80	239	239	0.00	986.60
28MAR80	240	240	22.17	1008.77
29MAR80	241	241	8.17	1016.94
30MAR80	242	242	17.50	1034.45
31MAR80	243	243	0.00	1034.45
01APR80	244	244	0.00	1034.45
02APR80	245	245	0.00	1034.45
03APR80	246	246	14.00	1048.45
04APR80	247	247	4.67	1053.12
05APR80	248	248	0.00	1053.12
06APR80	249	249	0.00	1053.12
07APR80	250	250	0.00	1053.12
08APR80	251	251	38.51	1091.63
09APR80	252	252	0.00	1091.63
10APR80	253	253	0.00	1091.63
11APR80	254	254	0.00	1091.63
12APR80	255	255	1.17	1092.80

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
13APR80	256	256	7.00	1099.80
14APR80	257	257	21.01	1120.81
15APR80	258	258	3.50	1124.31
16APR80	259	259	1.17	1125.47
17APR80	260	260	0.00	1125.47
18APR80	261	261	0.00	1125.47
19APR80	262	262	0.00	1125.47
20APR80	263	263	0.00	1125.47
21APR80	264	264	0.00	1125.47
22APR80	265	265	0.00	1125.47
23APR80	266	266	0.00	1125.47
24APR80	267	267	0.00	1125.47
25APR80	268	268	0.00	1125.47
26APR80	269	269	4.67	1130.14
27APR80	270	270	0.00	1130.14
28APR80	271	271	12.84	1142.98
29APR80	272	272	0.00	1142.98
30APR80	273	273	17.50	1160.48
01MAY80	274	274	1.17	1161.65
02MAY80	275	275	0.00	1161.65
03MAY80	276	276	0.00	1161.65
04MAY80	277	277	0.00	1161.65
05MAY80	278	278	0.00	1161.65
06MAY80	279	279	0.00	1161.65
07MAY80	280	280	0.00	1161.65
08MAY80	281	281	0.00	1161.65
09MAY80	282	282	0.00	1161.65
10MAY80	283	283	0.00	1161.65
11MAY80	284	284	2.33	1163.98
12MAY80	285	285	12.84	1176.82
13MAY80	286	286	0.00	1176.82
14MAY80	287	287	3.50	1180.32

DATE	DAY(A).	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
15MAY80	288	288	0.00	1180.32
16MAY80	289	289	0.00	1180.32
17MAY80	290	290	11.67	1191.99
18MAY80	291	291	0.00	1191.99
19MAY80	292	292	9.34	1201.33
20MAY80	293	293	53.68	1255.01
21MAY80	294	294	0.00	1255.01
22MAY80	295	295	0.00	1255.01
23MAY80	296	296	0.00	1255.01
24MAY80	297	297	23.34	1278.35
25MAY80	298	298	1.17	1279.52
26MAY80	299	299	0.00	1279.52
27MAY80	300	300	0.00	1279.52
28MAY80	301	301	0.00	1279.52
29MAY80	302	302	0.00	1279.52
30MAY80	303	303	16.34	1295.86
31MAY80	304	304	28.01	1323.86
01JUN80	305	305	2.33	1326.20
02JUN80	306	306	35.01	1361.21
03JUN80	307	307	25.67	1386.88
04JUN80	308	308	0.00	1386.88
05JUN80	309	309	0.00	1386.88
06JUN80	310	310	16.34	1403.22
07JUN80	311	311	10.50	1413.72
08JUN80	312	312	0.00	1413.72
09JUN80	313	313	0.00	1413.72
10JUN80	314	314	0.00	1413.72
11JUN80	315	315	0.00	1413.72
12JUN80	316	316	0.00	1413.72
13JUN80	317	317	0.00	1413.72
14JUN80	318	318	0.00	1413.72
15JUN80	319	319	39.68	1453.40

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
16JUN80	320	320	0.00	1453.40
17JUN80	321	321	0.00	1453.40
18JUN80	322	322	0.00	1453.40
19JUN80	323	323	0.00	1453.40
20JUN80	324	324	0.00	1453.40
21JUN80	325	325	0.00	1453.40
22JUN80	326	326	0.00	1453.40
23JUN80	327	327	0.00	1453.40
24JUN80	328	328	0.00	1453.40
25JUN80	329	329	0.00	1453.40
26JUN80	330	330	0.00	1453.40
27JUN80	331	331	4.67	1458.07
28JUN80	332	332	0.00	1458.07
29JUN80	333	333	0.00	1458.07
30JUN80	334	334	2.33	1460.40
01JUL80	335	335	0.00	1460.40
02JUL80	336	336	0.00	1460.40
03JUL80	337	337	0.00	1460.40
04JUL80	338	338	11.67	1472.07
05JUL80	339	339	0.00	1472.07
06JUL80	340	340	0.00	1472.07
07JUL80	341	341	0.00	1472.07
08JUL80	342	342	28.01	1500.08
09JUL80	343	343	21.01	1521.09
10JUL80	344	344	0.00	1521.09
11JUL80	345	345	0.00	1521.09
12JUL80	346	346	45.51	1566.60
13JUL80	347	347	0.00	1566.60
14JUL80	348	348	0.00	1566.60
15JUL80	349	349	0.00	1566.60
16JUL80	350	350	0.00	1566.60
17JUL80	351	351	0.00	1566.60

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
18JUL80	352	352	0.00	1566.60
19JUL80	353	353	0.00	1566.60
20JUL80	354	354	28.01	1594.61
21JUL80	355	355	7.00	1601.61
22JUL80	356	356	0.00	1601.61
23JUL80	357	357	0.00	1601.61
24JUL80	358	358	0.00	1601.61
25JUL80	359	359	0.00	1601.61
26JUL80	360	360	0.00	1601.61
27JUL80	361	361	23.34	1624.95
28JUL80	362	362	0.00	1624.95
29JUL80	363	363	0.00	1624.95
30JUL80	364	364	0.00	1624.95
31JUL80	365	365	0.00	1624.95
01AUG80	366	366	0.00	1624.95
02AUG80	367	367	9.34	1634.29
03AUG80	368	368	0.00	1634.29
04AUG80	369	369	2.33	1636.62
05AUG80	370	370	0.00	1636.62
06AUG80	371	371	0.00	1636.62
07AUG80	372	372	0.00	1636.62
08AUG80	373	373	0.00	1636.62
09AUG80	374	374	4.67	1641.29
10AUG80	375	375	35.01	1676.30
11AUG80	376	376	56.02	1732.31
12AUG80	377	377	17.50	1749.82
13AUG80	378	378	0.00	1749.82
14AUG80	379	379	0.00	1749.82
15AUG80	380	380	14.00	1763.82
16AUG80	381	381	0.00	1763.82
17AUG80	382	382	0.00	1763.82
18AUG80	383	383	116.70	1880.52

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
19AUG80	384	384	0.00	1880.52
20AUG80	385	385	0.00	1880.52
21AUG80	386	386	0.00	1880.52
22AUG80	387	387	0.00	1880.52
23AUG80	388	388	0.00	1880.52
24AUG80	389	389	0.00	1880.52
25AUG80	390	390	0.00	1880.52
26AUG80	391	391	0.00	1880.52
27AUG80	392	392	0.00	1880.52
28AUG80	393	393	0.00	1880.52
29AUG80	394	394	0.00	1880.52
30AUG80	395	395	0.00	1880.52
31AUG80	396	396	0.00	1880.52
01SEP80	397	397	0.00	1880.52
02SEP80	398	398	0.00	1880.52
03SEP80	399	399	0.00	1880.52
04SEP80	400	400	3.50	1884.02
05SEP80	401	401	22.17	1906.20
06SEP80	402	402	0.00	1906.20
07SEP80	403	403	2.33	1908.53
08SEP80	404	404	0.00	1908.53
09SEP80	405	405	0.00	1908.53
10SEP80	406	406	4.67	1913.20
11SEP80	407	407	0.00	1913.20
12SEP80	408	408	0.00	1913.20
13SEP80	409	409	0.00	1913.20
14SEP80	410	410	2.33	1915.53
15SEP80	411	411	10.50	1926.04
16SEP80	412	412	0.00	1926.04
17SEP80	413	413	0.00	1926.04
18SEP80	414	414	0.00	1926.04
19SEP80	415	415	0.00	1926.04

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
20SEP80	416	416	0.00	1926.04
21SEP80	417	417	1.17	1927.20
22SEP80	418	418	17.50	1944.71
23SEP80	419	419	3.50	1948.21
24SEP80	420	420	0.00	1948.21
25SEP80	421	421	0.00	1948.21
26SEP80	422	422	0.00	1948.21
27SEP80	423	423	0.00	1948.21
28SEP80	424	424	0.00	1948.21
29SEP80	425	425	0.00	1948.21
30SEP80	426	426	0.00	1948.21
01OCT80	427	427	0.00	1948.21
02OCT80	428	428	0.00	1948.21
03OCT80	429	429	2.33	1950.54
04OCT80	430	430	11.67	1962.21
05OCT80	431	431	0.00	1962.21
06OCT80	432	432	0.00	1962.21
07OCT80	433	433	0.00	1962.21
08OCT80	434	434	0.00	1962.21
09OCT80	435	435	0.00	1962.21
10OCT80	436	436	0.00	1962.21
11OCT80	437	437	1.17	1963.38
12OCT80	438	438	0.00	1963.38
13OCT80	439	439	0.00	1963.38
14OCT80	440	440	0.00	1963.38
15OCT80	441	441	0.00	1963.38
16OCT80	442	442	0.00	1963.38
17OCT80	443	443	0.00	1963.38
18OCT80	444	444	9.34	1972.72
19OCT80	445	445	0.00	1972.72
20OCT80	446	446	0.00	1972.72
21OCT80	447	447	0.00	1972.72

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
22OCT80	448	448	0.00	1972.72
23OCT80	449	449	0.00	1972.72
24OCT80	450	450	25.67	1998.39
25OCT80	451	451	8.17	2006.56
26OCT80	452	452	0.00	2006.56
27OCT80	453	453	2.33	2008.89
28OCT80	454	454	0.00	2008.89
29OCT80	455	455	0.00	2008.89
30OCT80	456	456	0.00	2008.89
31OCT80	457	457	0.00	2008.89
01NOV80	458	458	0.00	2008.89
02NOV80	459	459	0.00	2008.89
03NOV80	460	460	0.00	2008.89
04NOV80	461	461	2.33	2011.23
05NOV80	462	462	0.00	2011.23
06NOV80	463	463	0.00	2011.23
07NOV80	464	464	0.00	2011.23
08NOV80	465	465	4.67	2015.89
09NOV80	466	466	1.17	2017.06
10NOV80	467	467	0.00	2017.06
11NOV80	468	468	0.00	2017.06
12NOV80	469	469	0.00	2017.06
13NOV80	470	470	0.00	2017.06
14NOV80	471	471	0.00	2017.06
15NOV80	472	472	2.33	2019.40
16NOV80	473	473	0.00	2019.40
17NOV80	474	474	33.84	2053.24
18NOV80	475	475	5.83	2059.07
19NOV80	476	476	0.00	2059.07
20NOV80	477	477	0.00	2059.07
21NOV80	478	478	0.00	2059.07
22NOV80	479	479	0.00	2059.07

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
23NOV80	480	480	0.00	2059.07
24NOV80	481	481	29.17	2088.25
25NOV80	482	482	1.17	2089.42
26NOV80	483	483	0.00	2089.42
27NOV80	484	484	0.00	2089.42
28NOV80	485	485	0.00	2089.42
29NOV80	486	486	3.50	2092.92
30NOV80	487	487	3.50	2096.42
01DEC80	488	488	0.00	2096.42
02DEC80	489	489	8.17	2104.59
03DEC80	490	490	0.00	2104.59
04DEC80	491	491	0.00	2104.59
05DEC80	492	492	3.50	2108.09
06DEC80	493	493	0.00	2108.09
07DEC80	494	494	5.83	2113.92
08DEC80	495	495	0.00	2113.92
09DEC80	496	496	11.67	2125.59
10DEC80	497	497	0.00	2125.59
11DEC80	498	498	0.00	2125.59
12DEC80	499	499	2.33	2127.93
13DEC80	500	500	0.00	2127.93
14DEC80	501	501	0.00	2127.93
15DEC80	502	502	1.17	2129.09
16DEC80	503	503	0.00	2129.09
17DEC80	504	504	0.00	2129.09
18DEC80	505	505	0.00	2129.09
19DEC80	506	506	3.50	2132.59
20DEC80	507	507	0.00	2132.59
21DEC80	508	508	0.00	2132.59
22DEC80	509	509	0.00	2132.59
23DEC80	510	510	0.00	2132.59
24DEC80	511	511	2.33	2134.93

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
25DEC80	512	512	0.00	2134.93
26DEC80	513	513	0.00	2134.93
27DEC80	514	514	0.00	2134.93
28DEC80	515	515	2.33	2137.26
29DEC80	516	516	7.00	2144.26
30DEC80	517	517	0.00	2144.26
31DEC80	518	518	0.00	2144.26
01JAN81	519	519	0.00	2144.26
02JAN81	520	520	0.00	2144.26
03JAN81	521	521	0.00	2144.26
04JAN81	522	522	0.00	2144.26
05JAN81	523	523	0.00	2144.26
06JAN81	524	524	0.00	2144.26
07JAN81	525	525	0.00	2144.26
08JAN81	526	526	0.00	2144.26
09JAN81	527	527	0.00	2144.26
10JAN81	528	528	0.00	2144.26
11JAN81	529	529	0.00	2144.26
12JAN81	530	530	0.00	2144.26
13JAN81	531	531	0.00	2144.26
14JAN81	532	532	0.00	2144.26
15JAN81	533	533	4.67	2148.93
16JAN81	534	534	0.00	2148.93
01JUN81	670	535	0.00	2148.93
02JUN81	671	536	11.67	2160.60
03JUN81	672	537	11.67	2172.27
04JUN81	673	538	14.00	2186.28
05JUN81	674	539	11.67	2197.95
06JUN81	675	540	11.67	2209.62
07JUN81	676	541	11.67	2221.29
08JUN81	677	542	11.67	2232.96
09JUN81	678	543	11.67	2244.63

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
10JUN81	679	544	11.67	2256.30
11JUN81	680	545	11.67	2267.97
12JUN81	681	546	11.67	2279.64
13JUN81	682	547	11.67	2291.31
14JUN81	683	548	11.67	2302.98
15JUN81	684	549	11.67	2314.65
16JUN81	685	550	25.67	2340.32
17JUN81	686	551	0.00	2340.32
18JUN81	687	552	0.00	2340.32
19JUN81	688	553	0.00	2340.32
20JUN81	689	554	0.00	2340.32
21JUN81	690	555	14.00	2354.32
22JUN81	691	556	7.00	2361.33
23JUN81	692	557	0.00	2361.33
24JUN81	693	558	0.00	2361.33
25JUN81	694	559	38.51	2399.84
26JUN81	695	560	0.00	2399.84
27JUN81	696	561	0.00	2399.84
28JUN81	697	562	0.00	2399.84
29JUN81	698	563	0.00	2399.84
30JUN81	699	564	14.00	2413.84
01JUL81	700	565	0.00	2413.84
02JUL81	701	566	0.00	2413.84
03JUL81	702	567	0.00	2413.84
04JUL81	703	568	0.00	2413.84
05JUL81	704	569	9.34	2423.18
06JUL81	705	570	0.00	2423.18
07JUL81	706	571	0.00	2423.18
08JUL81	707	572	0.00	2423.18
09JUL81	708	573	0.00	2423.18
10JUL81	709	574	0.00	2423.18
11JUL81	710	575	0.00	2423.18

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
12JUL81	711	576	0.00	2423.18
13JUL81	712	577	25.67	2448.85
14JUL81	713	578	0.00	2448.85
15JUL81	714	579	0.00	2448.85
16JUL81	715	580	0.00	2448.85
17JUL81	716	581	0.00	2448.85
18JUL81	717	582	0.00	2448.85
19JUL81	718	583	0.00	2448.85
20JUL81	719	584	0.00	2448.85
21JUL81	720	585	42.01	2490.86
22JUL81	721	586	0.00	2490.86
23JUL81	722	587	0.00	2490.86
24JUL81	723	588	8.17	2499.03
25JUL81	724	589	0.00	2499.03
26JUL81	725	590	3.50	2502.53
27JUL81	726	591	0.00	2502.53
28JUL81	727	592	25.67	2528.21
29JUL81	728	593	12.84	2541.04
30JUL81	729	594	0.00	2541.04
31JUL81	730	595	0.00	2541.04
01AUG81	731	596	0.00	2541.04
02AUG81	732	597	0.00	2541.04
03AUG81	733	598	0.00	2541.04
04AUG81	734	599	11.67	2552.71
05AUG81	735	600	0.00	2552.71
06AUG81	736	601	19.84	2572.55
07AUG81	737	602	0.00	2572.55
08AUG81	738	603	0.00	2572.55
09AUG81	739	604	0.00	2572.55
10AUG81	740	605	0.00	2572.55
11AUG81	741	606	0.00	2572.55
12AUG81	742	607	0.00	2572.55

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
13AUG81	743	608	0.00	2572.55
14AUG81	744	609	0.00	2572.55
15AUG81	745	610	0.00	2572.55
16AUG81	746	611	3.50	2576.05
17AUG81	747	612	0.00	2576.05
18AUG81	748	613	0.00	2576.05
19AUG81	749	614	0.00	2576.05
20AUG81	750	615	0.00	2576.05
21AUG81	751	616	0.00	2576.05
22AUG81	752	617	0.00	2576.05
23AUG81	753	618	0.00	2576.05
24AUG81	754	619	0.00	2576.05
25AUG81	755	620	0.00	2576.05
26AUG81	756	621	0.00	2576.05
27AUG81	757	622	0.00	2576.05
28AUG81	758	623	0.00	2576.05
29AUG81	759	624	0.00	2576.05
30AUG81	760	625	3.50	2579.56
31AUG81	761	626	4.67	2584.22
01SEP81	762	627	11.67	2595.89
02SEP81	763	628	3.50	2599.39
03SEP81	764	629	7.00	2606.40
04SEP81	765	630	4.67	2611.06
05SEP81	766	631	0.00	2611.06
06SEP81	767	632	0.00	2611.06
07SEP81	768	633	0.00	2611.06
08SEP81	769	634	11.67	2622.73
09SEP81	770	635	0.00	2622.73
10SEP81	771	636	0.00	2622.73
11SEP81	772	637	0.00	2622.73
12SEP81	773	638	0.00	2622.73
13SEP81	774	639	0.00	2622.73

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
14SEP81	775	640	16.34	2639.07
15SEP81	776	641	17.50	2656.58
16SEP81	777	642	10.50	2667.08
17SEP81	778	643	0.00	2667.08
18SEP81	779	644	0.00	2667.08
19SEP81	780	645	0.00	2667.08
20SEP81	781	646	0.00	2667.08
21SEP81	782	647	0.00	2667.08
22SEP81	783	648	0.00	2667.08
23SEP81	784	649	0.00	2667.08
24SEP81	785	650	0.00	2667.08
25SEP81	786	651	0.00	2667.08
26SEP81	787	652	0.00	2667.08
27SEP81	788	653	0.00	2667.08
28SEP81	789	654	0.00	2667.08
29SEP81	790	655	0.00	2667.08
30SEP81	791	656	0.00	2667.08
01OCT81	792	657	0.00	2667.08
02OCT81	793	658	5.83	2672.92
03OCT81	794	659	0.00	2672.92
04OCT81	795	660	0.00	2672.92
05OCT81	796	661	0.00	2672.92
06OCT81	797	662	7.00	2679.92
07OCT81	798	663	0.00	2679.92
08OCT81	799	664	0.00	2679.92
09OCT81	800	665	0.00	2679.92
10OCT81	801	666	0.00	2679.92
11OCT81	802	667	0.00	2679.92
12OCT81	803	668	0.00	2679.92
13OCT81	804	669	0.00	2679.92
14OCT81	805	670	0.00	2679.92
15OCT81	806	671	0.00	2679.92

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
16OCT81	807	672	0.00	2679.92
17OCT81	808	673	0.00	2679.92
18OCT81	809	674	4.67	2684.59
19OCT81	810	675	5.83	2690.42
20OCT81	811	676	0.00	2690.42
21OCT81	812	677	0.00	2690.42
22OCT81	813	678	0.00	2690.42
23OCT81	814	679	16.34	2706.76
24OCT81	815	680	0.00	2706.76
25OCT81	816	681	3.50	2710.26
26OCT81	817	682	24.51	2734.77
27OCT81	818	683	33.84	2768.61
28OCT81	819	684	0.00	2768.61
29OCT81	820	685	0.00	2768.61
30OCT81	821	686	0.00	2768.61
31OCT81	822	687	0.00	2768.61
01NOV81	823	688	0.00	2768.61
02NOV81	824	689	0.00	2768.61
03NOV81	825	690	0.00	2768.61
04NOV81	826	691	0.00	2768.61
05NOV81	827	692	11.67	2780.28
06NOV81	828	693	0.00	2780.28

Appendix E

Attachment 4

Precipitation Record for the Alliance AFBC Field Cells

The precipitation rate for the Alliance AFBC cells were derived from the same rain gage as was used for the Exxon PFBC and control cells. The data were entered into the SAS data base and converted to volumes. Since the AFBC cells (13 and 17) were never covered, 'day (A)' (actual) and 'day (O)' (operational) are identical. They both reflect duration in days from the date of the first sampling event.

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DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
16MAR80	0	0	177.85	177.85
17MAR80	1	1	17.50	195.36
17MAR80	1	1	59.28	254.64
18MAR80	2	2	2.33	256.97
18MAR80	2	2	59.28	316.26
19MAR80	3	3	0.00	316.26
19MAR80	3	3	118.57	434.82
20MAR80	4	4	0.00	434.82
21MAR80	5	5	8.17	442.99
22MAR80	6	6	0.00	442.99
23MAR80	7	7	0.00	442.99
24MAR80	8	8	7.00	450.00
25MAR80	9	9	0.00	450.00
26MAR80	10	10	0.00	450.00
27MAR80	11	11	0.00	450.00
28MAR80	12	12	22.17	472.17
29MAR80	13	13	8.17	480.34
30MAR80	14	14	17.50	497.84
31MAR80	15	15	0.00	497.84
01APR80	16	16	0.00	497.84
02APR80	17	17	0.00	497.84
03APR80	18	18	14.00	511.85
04APR80	19	19	4.67	516.51
05APR80	20	20	0.00	516.51
06APR80	21	21	0.00	516.51
07APR80	22	22	0.00	516.51
08APR80	23	23	38.51	555.03
09APR80	24	24	0.00	555.03
10APR80	25	25	0.00	555.03
11APR80	26	26	0.00	555.03
12APR80	27	27	1.17	556.19
13APR80	28	28	7.00	563.19
14APR80	29	29	21.01	584.20

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
15APR80	30	30	3.50	587.70
16APR80	31	31	1.17	588.87
17APR80	32	32	0.00	588.87
18APR80	33	33	0.00	588.87
19APR80	34	34	0.00	588.87
20APR80	35	35	0.00	588.87
21APR80	36	36	0.00	588.87
22APR80	37	37	0.00	588.87
23APR80	38	38	0.00	588.87
24APR80	39	39	0.00	588.87
25APR80	40	40	0.00	588.87
26APR80	41	41	4.67	593.54
27APR80	42	42	0.00	593.54
28APR80	43	43	12.84	606.37
29APR80	44	44	0.00	606.37
30APR80	45	45	17.50	623.88
01MAY80	46	46	1.17	625.05
02MAY80	47	47	0.00	625.05
03MAY80	48	48	0.00	625.05
04MAY80	49	49	0.00	625.05
05MAY80	50	50	0.00	625.05
06MAY80	51	51	0.00	625.05
07MAY80	52	52	0.00	625.05
08MAY80	53	53	0.00	625.05
09MAY80	54	54	0.00	625.05
10MAY80	55	55	0.00	625.05
11MAY80	56	56	2.33	627.38
12MAY80	57	57	12.84	640.22
13MAY80	58	58	0.00	640.22
14MAY80	59	59	3.50	643.72
15MAY80	60	60	0.00	643.72
16MAY80	61	61	0.00	643.72

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DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
17MAY80	62	62	11.67	655.39
18MAY80	63	63	0.00	655.39
19MAY80	64	64	9.34	664.72
20MAY80	65	65	53.68	718.41
21MAY80	66	66	0.00	718.41
22MAY80	67	67	0.00	718.41
23MAY80	68	68	0.00	718.41
24MAY80	69	69	23.34	741.75
25MAY80	70	70	1.17	742.91
26MAY80	71	71	0.00	742.91
27MAY80	72	72	0.00	742.91
28MAY80	73	73	0.00	742.91
29MAY80	74	74	0.00	742.91
30MAY80	75	75	16.34	759.25
31MAY80	76	76	28.01	787.26
01JUN80	77	77	2.33	789.59
02JUN80	78	78	35.01	824.60
03JUN80	79	79	25.67	850.28
04JUN80	80	80	0.00	850.28
05JUN80	81	81	0.00	850.28
06JUN80	82	82	16.34	866.61
07JUN80	83	83	10.50	877.12
08JUN80	84	84	0.00	877.12
09JUN80	85	85	0.00	877.12
10JUN80	86	86	0.00	877.12
11JUN80	87	87	0.00	877.12
12JUN80	88	88	0.00	877.12
13JUN80	89	89	0.00	877.12
14JUN80	90	90	0.00	877.12
15JUN80	91	91	39.68	916.80
16JUN80	92	92	0.00	916.80
17JUN80	93	93	0.00	916.80

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
18JUN80	94	94	0.00	916.80
19JUN80	95	95	0.00	916.80
20JUN80	96	96	0.00	916.80
21JUN80	97	97	0.00	916.80
22JUN80	98	98	0.00	916.80
23JUN80	99	99	0.00	916.80
24JUN80	100	100	0.00	916.80
25JUN80	101	101	0.00	916.80
26JUN80	102	102	0.00	916.80
27JUN80	103	103	4.67	921.46
28JUN80	104	104	0.00	921.46
29JUN80	105	105	0.00	921.46
30JUN80	106	106	2.33	923.80
01JUL80	107	107	0.00	923.80
02JUL80	108	108	0.00	923.80
03JUL80	109	109	0.00	923.80
04JUL80	110	110	11.67	935.47
05JUL80	111	111	0.00	935.47
06JUL80	112	112	0.00	935.47
07JUL80	113	113	0.00	935.47
08JUL80	114	114	28.01	963.48
09JUL80	115	115	21.01	984.48
10JUL80	116	116	0.00	984.48
11JUL80	117	117	0.00	984.48
12JUL80	118	118	45.51	1029.99
13JUL80	119	119	0.00	1029.99
14JUL80	120	120	0.00	1029.99
15JUL80	121	121	0.00	1029.99
16JUL80	122	122	0.00	1029.99
17JUL80	123	123	0.00	1029.99
18JUL80	124	124	0.00	1029.99
19JUL80	125	125	0.00	1029.99

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
20JUL80	126	126	28.01	1058.00
21JUL80	127	127	7.00	1065.00
22JUL80	128	128	0.00	1065.00
23JUL80	129	129	0.00	1065.00
24JUL80	130	130	0.00	1065.00
25JUL80	131	131	0.00	1065.00
26JUL80	132	132	0.00	1065.00
27JUL80	133	133	23.34	1088.34
28JUL80	134	134	0.00	1088.34
29JUL80	135	135	0.00	1088.34
30JUL80	136	136	0.00	1088.34
31JUL80	137	137	0.00	1088.34
01AUG80	138	138	0.00	1088.34
02AUG80	139	139	9.34	1097.68
03AUG80	140	140	0.00	1097.68
04AUG80	141	141	2.33	1100.01
05AUG80	142	142	0.00	1100.01
06AUG80	143	143	0.00	1100.01
07AUG80	144	144	0.00	1100.01
08AUG80	145	145	0.00	1100.01
09AUG80	146	146	4.67	1104.68
10AUG80	147	147	35.01	1139.69
11AUG80	148	148	56.02	1195.71
12AUG80	149	149	17.50	1213.21
13AUG80	150	150	0.00	1213.21
14AUG80	151	151	0.00	1213.21
15AUG80	152	152	14.00	1227.22
16AUG80	153	153	0.00	1227.22
17AUG80	154	154	0.00	1227.22
18AUG80	155	155	116.70	1343.92
19AUG80	156	156	0.00	1343.92
20AUG80	157	157	0.00	1343.92

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
21AUG80	158	158	0.00	1343.92
22AUG80	159	159	0.00	1343.92
23AUG80	160	160	0.00	1343.92
24AUG80	161	161	0.00	1343.92
25AUG80	162	162	0.00	1343.92
26AUG80	163	163	0.00	1343.92
27AUG80	164	164	0.00	1343.92
28AUG80	165	165	0.00	1343.92
29AUG80	166	166	0.00	1343.92
30AUG80	167	167	0.00	1343.92
31AUG80	168	168	0.00	1343.92
01SEP80	169	169	0.00	1343.92
02SEP80	170	170	0.00	1343.92
03SEP80	171	171	0.00	1343.92
04SEP80	172	172	3.50	1347.42
05SEP80	173	173	22.17	1369.59
06SEP80	174	174	0.00	1369.59
07SEP80	175	175	2.33	1371.93
08SEP80	176	176	0.00	1371.93
09SEP80	177	177	0.00	1371.93
10SEP80	178	178	4.67	1376.59
11SEP80	179	179	0.00	1376.59
12SEP80	180	180	0.00	1376.59
13SEP80	181	181	0.00	1376.59
14SEP80	182	182	2.33	1378.93
15SEP80	183	183	10.50	1389.43
16SEP80	184	184	0.00	1389.43
17SEP80	185	185	0.00	1389.43
18SEP80	186	186	0.00	1389.43
19SEP80	187	187	0.00	1389.43
20SEP80	188	188	0.00	1389.43
21SEP80	189	189	1.17	1390.60

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
22SEP80	190	190	17.50	1408.10
23SEP80	191	191	3.50	1411.60
24SEP80	192	192	0.00	1411.60
25SEP80	193	193	0.00	1411.60
26SEP80	194	194	0.00	1411.60
27SEP80	195	195	0.00	1411.60
28SEP80	196	196	0.00	1411.60
29SEP80	197	197	0.00	1411.60
30SEP80	198	198	0.00	1411.60
01OCT80	199	199	0.00	1411.60
02OCT80	200	200	0.00	1411.60
03OCT80	201	201	2.33	1413.94
04OCT80	202	202	11.67	1425.61
05OCT80	203	203	0.00	1425.61
06OCT80	204	204	0.00	1425.61
07OCT80	205	205	0.00	1425.61
08OCT80	206	206	0.00	1425.61
09OCT80	207	207	0.00	1425.61
10OCT80	208	208	0.00	1425.61
11OCT80	209	209	1.17	1426.77
12OCT80	210	210	0.00	1426.77
13OCT80	211	211	0.00	1426.77
14OCT80	212	212	0.00	1426.77
15OCT80	213	213	0.00	1426.77
16OCT80	214	214	0.00	1426.77
17OCT80	215	215	0.00	1426.77
18OCT80	216	216	9.34	1436.11
19OCT80	217	217	0.00	1436.11
20OCT80	218	218	0.00	1436.11
21OCT80	219	219	0.00	1436.11
22OCT80	220	220	0.00	1436.11
23OCT80	221	221	0.00	1436.11

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
24OCT80	222	222	25.67	1461.78
25OCT80	223	223	8.17	1469.95
26OCT80	224	224	0.00	1469.95
27OCT80	225	225	2.33	1472.29
28OCT80	226	226	0.00	1472.29
29OCT80	227	227	0.00	1472.29
30OCT80	228	228	0.00	1472.29
31OCT80	229	229	0.00	1472.29
01NOV80	230	230	0.00	1472.29
02NOV80	231	231	0.00	1472.29
03NOV80	232	232	0.00	1472.29
04NOV80	233	233	2.33	1474.62
05NOV80	234	234	0.00	1474.62
06NOV80	235	235	0.00	1474.62
07NOV80	236	236	0.00	1474.62
08NOV80	237	237	4.67	1479.29
09NOV80	238	238	1.17	1480.46
10NOV80	239	239	0.00	1480.46
11NOV80	240	240	0.00	1480.46
12NOV80	241	241	0.00	1480.46
13NOV80	242	242	0.00	1480.46
14NOV80	243	243	0.00	1480.46
15NOV80	244	244	2.33	1482.79
16NOV80	245	245	0.00	1482.79
17NOV80	246	246	33.84	1516.63
18NOV80	247	247	5.83	1522.47
19NOV80	248	248	0.00	1522.47
20NOV80	249	249	0.00	1522.47
21NOV80	250	250	0.00	1522.47
22NOV80	251	251	0.00	1522.47
23NOV80	252	252	0.00	1522.47
24NOV80	253	253	29.17	1551.64

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
25NOV80	254	254	1.17	1552.81
26NOV80	255	255	0.00	1552.81
27NOV80	256	256	0.00	1552.81
28NOV80	257	257	0.00	1552.81
29NOV80	258	258	3.50	1556.31
30NOV80	259	259	3.50	1559.81
01DEC80	260	260	0.00	1559.81
02DEC80	261	261	8.17	1567.98
03DEC80	262	262	0.00	1567.98
04DEC80	263	263	0.00	1567.98
05DEC80	264	264	3.50	1571.48
06DEC80	265	265	0.00	1571.48
07DEC80	266	266	5.83	1577.32
08DEC80	267	267	0.00	1577.32
09DEC80	268	268	11.67	1588.99
10DEC80	269	269	0.00	1588.99
11DEC80	270	270	0.00	1588.99
12DEC80	271	271	2.33	1591.32
13DEC80	272	272	0.00	1591.32
14DEC80	273	273	0.00	1591.32
15DEC80	274	274	1.17	1592.49
16DEC80	275	275	0.00	1592.49
17DEC80	276	276	0.00	1592.49
18DEC80	277	277	0.00	1592.49
19DEC80	278	278	3.50	1595.99
20DEC80	279	279	0.00	1595.99
21DEC80	280	280	0.00	1595.99
22DEC80	281	281	0.00	1595.99
23DEC80	282	282	0.00	1595.99
24DEC80	283	283	2.33	1598.32
25DEC80	284	284	0.00	1598.32
26DEC80	285	285	0.00	1598.32

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
27DEC80	286	286	0.00	1598.32
28DEC80	287	287	2.33	1600.66
29DEC80	288	288	7.00	1607.66
30DEC80	289	289	0.00	1607.66
31DEC80	290	290	0.00	1607.66
01JAN81	291	291	0.00	1607.66
02JAN81	292	292	0.00	1607.66
03JAN81	293	293	0.00	1607.66
04JAN81	294	294	0.00	1607.66
05JAN81	295	295	0.00	1607.66
06JAN81	296	296	0.00	1607.66
07JAN81	297	297	0.00	1607.66
08JAN81	298	298	0.00	1607.66
09JAN81	299	299	0.00	1607.66
10JAN81	300	300	0.00	1607.66
11JAN81	301	301	0.00	1607.66
12JAN81	302	302	0.00	1607.66
13JAN81	303	303	0.00	1607.66
14JAN81	304	304	0.00	1607.66
15JAN81	305	305	4.67	1612.33
16JAN81	306	306	0.00	1612.33
17JAN81	307	307	0.00	1612.33
18JAN81	308	308	0.00	1612.33
19JAN81	309	309	0.00	1612.33
20JAN81	310	310	4.67	1617.00
21JAN81	311	311	14.00	1631.00
22JAN81	312	312	3.50	1634.50
23JAN81	313	313	0.00	1634.50
24JAN81	314	314	0.00	1634.50
25JAN81	315	315	0.00	1634.50
26JAN81	316	316	0.00	1634.50
27JAN81	317	317	0.00	1634.50

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
28JAN81	318	318	0.00	1634.50
29JAN81	319	319	0.00	1634.50
30JAN81	320	320	0.00	1634.50
31JAN81	321	321	0.00	1634.50
01FEB81	322	322	18.67	1653.17
02FEB81	323	323	21.01	1674.18
03FEB81	324	324	0.00	1674.18
04FEB81	325	325	0.00	1674.18
05FEB81	326	326	0.00	1674.18
06FEB81	327	327	2.33	1676.51
07FEB81	328	328	0.00	1676.51
08FEB81	329	329	2.33	1678.85
09FEB81	330	330	0.00	1678.85
10FEB81	331	331	7.00	1685.85
11FEB81	332	332	7.00	1692.85
12FEB81	333	333	0.00	1692.85
13FEB81	334	334	3.50	1696.35
14FEB81	335	335	0.00	1696.35
15FEB81	336	336	0.00	1696.35
16FEB81	337	337	0.00	1696.35
17FEB81	338	338	5.83	1702.19
18FEB81	339	339	0.00	1702.19
19FEB81	340	340	0.00	1702.19
20FEB81	341	341	10.50	1712.69
21FEB81	342	342	17.50	1730.19
22FEB81	343	343	0.00	1730.19
23FEB81	344	344	24.51	1754.70
24FEB81	345	345	0.00	1754.70
25FEB81	346	346	0.00	1754.70
26FEB81	347	347	0.00	1754.70
27FEB81	348	348	0.00	1754.70
28FEB81	349	349	16.34	1771.04

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
01MAR81	350	350	0.00	1771.04
02MAR81	351	351	0.00	1771.04
03MAR81	352	352	0.00	1771.04
04MAR81	353	353	0.00	1771.04
05MAR81	354	354	23.34	1794.38
06MAR81	355	355	0.00	1794.38
07MAR81	356	356	0.00	1794.38
08MAR81	357	357	0.00	1794.38
09MAR81	358	358	0.00	1794.38
10MAR81	359	359	0.00	1794.38
11MAR81	360	360	4.67	1799.05
12MAR81	361	361	0.00	1799.05
13MAR81	362	362	0.00	1799.05
14MAR81	363	363	0.00	1799.05
15MAR81	364	364	0.00	1799.05
16MAR81	365	365	11.67	1810.72
17MAR81	366	366	2.33	1813.05
18MAR81	367	367	0.00	1813.05
19MAR81	368	368	0.00	1813.05
20MAR81	369	369	3.50	1816.55
21MAR81	370	370	1.17	1817.72
22MAR81	371	371	0.00	1817.72
23MAR81	372	372	0.00	1817.72
24MAR81	373	373	0.00	1817.72
25MAR81	374	374	0.00	1817.72
26MAR81	375	375	0.00	1817.72
27MAR81	376	376	7.00	1824.72
28MAR81	377	377	1.17	1825.89
29MAR81	378	378	0.00	1825.89
30MAR81	379	379	3.50	1829.39
31MAR81	380	380	0.00	1829.39
01APR81	381	381	0.00	1829.39

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
02APR81	382	382	0.00	1829.39
03APR81	383	383	0.00	1829.39
04APR81	384	384	0.00	1829.39
05APR81	385	385	7.00	1836.39
06APR81	386	386	0.00	1836.39
07APR81	387	387	0.00	1836.39
08APR81	388	388	0.00	1836.39
09APR81	389	389	7.00	1843.39
10APR81	390	390	0.00	1843.39
11APR81	391	391	4.67	1848.06
12APR81	392	392	35.01	1883.07
13APR81	393	393	0.00	1883.07
14APR81	394	394	24.51	1907.58
15APR81	395	395	0.00	1907.58
16APR81	396	396	0.00	1907.58
17APR81	397	397	12.84	1920.42
18APR81	398	398	3.50	1923.92
19APR81	399	399	0.00	1923.92
20APR81	400	400	3.50	1927.42
21APR81	401	401	0.00	1927.42
22APR81	402	402	0.00	1927.42
23APR81	403	403	14.00	1941.42
24APR81	404	404	0.00	1941.42
25APR81	405	405	0.00	1941.42
26APR81	406	406	0.00	1941.42
27APR81	407	407	23.34	1964.76
28APR81	408	408	0.00	1964.76
29APR81	409	409	1.17	1965.93
30APR81	410	410	0.00	1965.93
01MAY81	411	411	10.50	1976.43
02MAY81	412	412	0.00	1976.43
03MAY81	413	413	0.00	1976.43

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
04MAY81	414	414	0.00	1976.43
05MAY81	415	415	0.00	1976.43
06MAY81	416	416	5.83	1982.27
07MAY81	417	417	0.00	1982.27
08MAY81	418	418	0.00	1982.27
09MAY81	419	419	0.00	1982.27
10MAY81	420	420	0.00	1982.27
11MAY81	421	421	9.34	1991.60
12MAY81	422	422	2.33	1993.94
13MAY81	423	423	0.00	1993.94
14MAY81	424	424	0.00	1993.94
15MAY81	425	425	35.01	2028.95
16MAY81	426	426	0.00	2028.95
17MAY81	427	427	0.00	2028.95
18MAY81	428	428	0.00	2028.95
19MAY81	429	429	37.34	2066.29
20MAY81	430	430	0.00	2066.29
21MAY81	431	431	0.00	2066.29
22MAY81	432	432	0.00	2066.29
23MAY81	433	433	0.00	2066.29
24MAY81	434	434	0.00	2066.29
25MAY81	435	435	0.00	2066.29
26MAY81	436	436	0.00	2066.29
27MAY81	437	437	3.50	2069.79
28MAY81	438	438	7.00	2076.79
29MAY81	439	439	0.00	2076.79
30MAY81	440	440	0.00	2076.79
31MAY81	441	441	26.84	2103.63
01JUN81	442	442	0.00	2103.63
02JUN81	443	443	11.67	2115.30
03JUN81	444	444	11.67	2126.97
04JUN81	445	445	14.00	2140.98

DATE	DAY(A)	DAY(D)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
05JUN81	446	446	11.67	2152.65
06JUN81	447	447	11.67	2164.32
07JUN81	448	448	11.67	2175.99
08JUN81	449	449	11.67	2187.66
09JUN81	450	450	11.67	2199.33
10JUN81	451	451	11.67	2211.00
11JUN81	452	452	11.67	2222.67
12JUN81	453	453	11.67	2234.34
13JUN81	454	454	11.67	2246.01
14JUN81	455	455	11.67	2257.68
15JUN81	456	456	11.67	2269.35
16JUN81	457	457	25.67	2295.02
17JUN81	458	458	0.00	2295.02
18JUN81	459	459	0.00	2295.02
19JUN81	460	460	0.00	2295.02
20JUN81	461	461	0.00	2295.02
21JUN81	462	462	14.00	2309.03
22JUN81	463	463	7.00	2316.03
23JUN81	464	464	0.00	2316.03
24JUN81	465	465	0.00	2316.03
25JUN81	466	466	38.51	2354.54
26JUN81	467	467	0.00	2354.54
27JUN81	468	468	0.00	2354.54
28JUN81	469	469	0.00	2354.54
29JUN81	470	470	0.00	2354.54
30JUN81	471	471	14.00	2368.54
01JUL81	472	472	0.00	2368.54
02JUL81	473	473	0.00	2368.54
03JUL81	474	474	0.00	2368.54
04JUL81	475	475	0.00	2368.54
05JUL81	476	476	9.34	2377.88
06JUL81	477	477	0.00	2377.88

DATE	DAY(A)	DAY(D)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
07JUL81	478	478	0.00	2377.88
08JUL81	479	479	0.00	2377.88
09JUL81	480	480	0.00	2377.88
10JUL81	481	481	0.00	2377.88
11JUL81	482	482	0.00	2377.88
12JUL81	483	483	0.00	2377.88
13JUL81	484	484	25.67	2403.55
14JUL81	485	485	0.00	2403.55
15JUL81	486	486	0.00	2403.55
16JUL81	487	487	0.00	2403.55
17JUL81	488	488	0.00	2403.55
18JUL81	489	489	0.00	2403.55
19JUL81	490	490	0.00	2403.55
20JUL81	491	491	0.00	2403.55
21JUL81	492	492	42.01	2445.57
22JUL81	493	493	0.00	2445.57
23JUL81	494	494	0.00	2445.57
24JUL81	495	495	8.17	2453.73
25JUL81	496	496	0.00	2453.73
26JUL81	497	497	3.50	2457.24
27JUL81	498	498	0.00	2457.24
28JUL81	499	499	25.67	2482.91
29JUL81	500	500	12.84	2495.75
30JUL81	501	501	0.00	2495.75
31JUL81	502	502	0.00	2495.75
01AUG81	503	503	0.00	2495.75
02AUG81	504	504	0.00	2495.75
03AUG81	505	505	0.00	2495.75
04AUG81	506	506	11.67	2507.42
05AUG81	507	507	0.00	2507.42
06AUG81	508	508	19.84	2527.26
07AUG81	509	509	0.00	2527.26

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
08AUG81	510	510	0.00	2527.26
09AUG81	511	511	0.00	2527.26
10AUG81	512	512	0.00	2527.26
11AUG81	513	513	0.00	2527.26
12AUG81	514	514	0.00	2527.26
13AUG81	515	515	0.00	2527.26
14AUG81	516	516	0.00	2527.26
15AUG81	517	517	0.00	2527.26
16AUG81	518	518	3.50	2530.76
17AUG81	519	519	0.00	2530.76
18AUG81	520	520	0.00	2530.76
19AUG81	521	521	0.00	2530.76
20AUG81	522	522	0.00	2530.76
21AUG81	523	523	0.00	2530.76
22AUG81	524	524	0.00	2530.76
23AUG81	525	525	0.00	2530.76
24AUG81	526	526	0.00	2530.76
25AUG81	527	527	0.00	2530.76
26AUG81	528	528	0.00	2530.76
27AUG81	529	529	0.00	2530.76
28AUG81	530	530	0.00	2530.76
29AUG81	531	531	0.00	2530.76
30AUG81	532	532	3.50	2534.26
31AUG81	533	533	4.67	2538.93
01SEP81	534	534	11.67	2550.60
02SEP81	535	535	3.50	2554.10
03SEP81	536	536	7.00	2561.10
04SEP81	537	537	4.67	2565.77
05SEP81	538	538	0.00	2565.77
06SEP81	539	539	0.00	2565.77
07SEP81	540	540	0.00	2565.77
08SEP81	541	541	11.67	2577.44

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
09SEP81	542	542	0.00	2577.44
10SEP81	543	543	0.00	2577.44
11SEP81	544	544	0.00	2577.44
12SEP81	545	545	0.00	2577.44
13SEP81	546	546	0.00	2577.44
14SEP81	547	547	16.34	2593.77
15SEP81	548	548	17.50	2611.28
16SEP81	549	549	10.50	2621.78
17SEP81	550	550	0.00	2621.78
18SEP81	551	551	0.00	2621.78
19SEP81	552	552	0.00	2621.78
20SEP81	553	553	0.00	2621.78
21SEP81	554	554	0.00	2621.78
22SEP81	555	555	0.00	2621.78
23SEP81	556	556	0.00	2621.78
24SEP81	557	557	0.00	2621.78
25SEP81	558	558	0.00	2621.78
26SEP81	559	559	0.00	2621.78
27SEP81	560	560	0.00	2621.78
28SEP81	561	561	0.00	2621.78
29SEP81	562	562	0.00	2621.78
30SEP81	563	563	0.00	2621.78
01OCT81	564	564	0.00	2621.78
02OCT81	565	565	5.83	2627.62
03OCT81	566	566	0.00	2627.62
04OCT81	567	567	0.00	2627.62
05OCT81	568	568	0.00	2627.62
06OCT81	569	569	7.00	2634.62
07OCT81	570	570	0.00	2634.62
08OCT81	571	571	0.00	2634.62
09OCT81	572	572	0.00	2634.62
10OCT81	573	573	0.00	2634.62

DATE	DAY(A)	DAY(O)	RAINFALL (LITERS)	CUMULATIVE RAINFALL
11OCT81	574	574	0.00	2634.62
12OCT81	575	575	0.00	2634.62
13OCT81	576	576	0.00	2634.62
14OCT81	577	577	0.00	2634.62
15OCT81	578	578	0.00	2634.62
16OCT81	579	579	0.00	2634.62
17OCT81	580	580	0.00	2634.62
18OCT81	581	581	4.67	2639.29
19OCT81	582	582	5.83	2645.12
20OCT81	583	583	0.00	2645.12
21OCT81	584	584	0.00	2645.12
22OCT81	585	585	0.00	2645.12
23OCT81	586	586	16.34	2661.46
24OCT81	587	587	0.00	2661.46
25OCT81	588	588	3.50	2664.96
26OCT81	589	589	24.51	2689.47
27OCT81	590	590	33.84	2723.31
28OCT81	591	591	0.00	2723.31
29OCT81	592	592	0.00	2723.31
30OCT81	593	593	0.00	2723.31
31OCT81	594	594	0.00	2723.31
01NOV81	595	595	0.00	2723.31
02NOV81	596	596	0.00	2723.31
03NOV81	597	597	0.00	2723.31
04NOV81	598	598	0.00	2723.31
05NOV81	599	599	11.67	2734.98
06NOV81	600	600	0.00	2734.98